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PREVENTION REFERENCE MANUAL:
CHEMICAL SPECIFIC
VOLUME 4: CONTROL OF ACCIDENTAL RELEASES OF AMMONIA (SCAQMD)

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ABSTRACT

The South Coast Air Quality Management District (SCAQMD) of southern California has developed a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and providing guidance to industry and communities. This manual summarizes technical information that will assist in identifying and therefore controlling release hazards specific to the SCAQMD associated with ammonia.

Ammonia gas has an IDLH (Immediately Dangerous to Life and Health) concentration of 500 ppm, which makes it an acute toxic hazard. To reduce the risk associated with an accidental release of ammonia, some of the potential causes of accidental releases that apply to processes using ammonia in the SCAQMD must be identified. Examples of such potential causes are identified, as are specific measures that may be taken to reduce the accidental release risk. These measures include recommendations on plant design practices, prevention, protection and mitigation technologies, and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation measures are provided.

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TABLE OF CONTENTS

Section			Page
ABSTRACT			iii
ACKNOWLEDGEMENTS			iv
FIGURES			vi
TABLES			vii
1	INTRODUCTION		1
	1.1	Background	1
	1.2	Purpose of This Manual	1
	1.3	Uses of Anhydrous Ammonia	2
	1.4	Organization of the Manual	3
2	CHEMICAL CHARACTERISTICS		4
	2.1	Physical Properties	4
	2.2	Chemical Properties and Reactivity	7
	2.3	Toxicological and Health Effects	8
3	FACILITY DESCRIPTIONS AND PROCESS HAZARDS		11
	3.1	Processing	11
		3.1.1 Recovery of Ammonia from Waste Water Treatment	11
		3.1.2 The Use of Ammonia in the Production of Resins	14
		3.1.3 The Use of Ammonia as a Refrigerant	16
		3.1.4 Neutralization of Acidic Waste Streams with Ammonia	19
		3.1.5 The Preparation of Ammonium Thiosulfate	20
		3.1.6 The Reduction of NO_x Emissions with Ammonia	22
	3.2	Repackaging	24
	3.3	Storage and Transfer	26
		3.3.1 Storage	26
		3.3.2 Transfer from Tank Cars and Trucks	28
		3.3.3 Transfer from Storage Vessels	30
		3.3.4 Transporting Ammonia Storage Containers	31
	3.4	Potential Causes of Releases	31
		3.4.1 Process Causes	32
		3.4.2 Equipment Causes	32
		3.4.3 Operational Causes	34
4	HAZARDS PREVENTION AND CONTROL		35
	4.1	General Considerations	35
	4.2	Process Design	36
	4.3	Physical Plant Design	36
		4.3.1 Equipment	38
		4.3.2 Plant Siting and Layout	53
		4.3.3 Transfer and Transport Facilities	55
	4.4	Protection Technologies	55
		4.4.1 Enclosures	56
		4.4.2 Scrubbers	57
		4.4.3 Flares	58

TABLE OF CONTENTS (Continued)

Section		Page
	4.5 Mitigation Technologies	60
	4.5.1 Secondary Containment Systems	63
	4.5.2 Flotation Devices and Foams	67
	4.5.3 Mitigation Techniques for Ammonia Vapor	68
	4.6 Operation and Maintenance Practices	70
	4.7 Control Effectiveness	70
	4.8 Illustrative Cost Estimates For Controls	71
	4.8.1 Prevention and Protection Measures	71
	4.8.2 Levels of Control	74
	4.8.3 Cost Summaries	75
	4.8.4 Equipment Specifications and Detailed Costs	75
	4.8.5 Methodology	100
5	REFERENCES	109
APPENDIX A - GLOSSARY		114
APPENDIX B - METRIC (SI) CONVERSION FACTORS		118

FIGURES

Number		Page
3-1	Conceptual diagram of the "WWT" waste water treatment process	13
3-2	Conceptual diagram of typical acrylonitrile process	15
3-3	Basic vapor compression refrigeration cycle	17
3-4	Conceptual diagram of typical ammonium thiosulfate process	21
3-5	Schematic of selective catalytic reduction (SCR) process	23

TABLES

Number		Page
2-1	Physical Properties of Anhydrous Ammonia	5
2-2	Exposure Limits For Anhydrous Ammonia	9
2-3	Predicted Human Health Effects of Exposure to Various Concentrations of Anhydrous Ammonia	10
4-1	Some Process Design Considerations for Processing Involving Anhydrous Ammonia	37
4-2	Maximum Safe Volume of Liquid Ammonia in Nonrefrigerated Storage Containers at Various Temperatures	44
4-3	Important Considerations for Using Flares to Prevent Accidental Chemical Releases	61
4-4	Examples of Major Prevention and Protection Measures for Ammonia Releases	72
4-5	Estimated Typical Costs of Major Prevention and Protection Measures for Ammonia Releases	73
4-6	Summary Cost Estimates of Potential Levels of Controls for Ammonia Storage Tank and Stripper	76
4-7	Example of Levels of Control for Ammonia Storage Tank	77
4-8	Example of Levels of Control for Ammonia Stripper	79
4-9	Estimated Typical Capital and Annual Costs Associated With Baseline Ammonia Storage System	81
4-10	Estimated Typical Capital and Annual Costs Associated With Level 1 Ammonia Storage System	82
4-11	Estimated Typical Capital and Annual Costs Associated With Level 2 Ammonia Storage System	84
4-12	Estimated Typical Capital and Annual Costs Associated With Baseline Waste Water Treatment Ammonia Stripper	86
4-13	Estimated Typical Capital and Annual Costs Associated With Level 1 Waste Water Treatment Ammonia Stripper	87
4-14	Estimated Typical Capital and Annual Costs Associated With Level 2 Waste Water Treatment Ammonia Stripper	88

TABLES (Continued)

Section		Page
4-15	Equipment Specifications Associated With Ammonia Storage System	89
4-16	Material and Labor Costs Associated With Baseline Ammonia Storage System	91
4-17	Material and Labor Costs Associated With Level 1 Ammonia Storage System	92
4-18	Material and Labor Costs Associated With Level 2 Ammonia Storage System	93
4-19	Equipment Specifications Associated With Waste Water Treatment Ammonia Stripping Process	94
4-20	Material and Labor Costs Associated With Baseline Waste Water Treatment Ammonia Stripper	95
4-21	Material and Labor Costs Associated With Level 1 Waste Water Treatment Ammonia Stripper	96
4-22	Material and Labor Costs Associated With Level 2 Waste Water Treatment Ammonia Stripper	98
4-23	Format For Total Fixed Capital Cost	101
4-24	Format For Total Annual Cost	103
4-25	Format For Installation Costs	108

SECTION 1
INTRODUCTION

1.1 BACKGROUND

Recognizing the risk associated with accidental releases of air toxics in southern California, the South Coast Air Quality Management District (SCAQMD) conducted a study in 1985 to determine the presence, quantities, and uses of dangerous chemicals in the SCAQMD, which comprises Los Angeles, Orange, San Bernadino, and Riverside Counties. This study resulted in a report entitled "South Coast Air Basin Accidental Toxic Air Emissions Study," which outlined an overall strategy for reducing the potential for a major toxic chemical release incident.

The strategy includes: monitoring industry activities that require the storage, handling, and use of certain chemicals; using the best technical information available; guiding industry and communities in minimizing the potential for accidental releases and the consequences of any releases that might occur.

Historically, there do not appear to have been any significant releases of ammonia in the SCAQMD. Major releases of ammonia have occurred elsewhere in the past fifteen years, however, involving numerous injuries and a significant number of fatalities. Primary sources of these releases include pressurized pipeline ruptures, failed storage tanks, and road tanker accidents.

1.2 PURPOSE OF THIS MANUAL

This manual compiles technical information on ammonia that emphasizes the prevention of accidental releases of this chemical. The manual summarizes issues relating to release prevention associated with the storage and handling

of ammonia and with process operations involving anhydrous ammonia as it is used in the SCAQMD. (Note: Throughout this manual, "ammonia" refers only to anhydrous ammonia and not to aqueous or "aqua" ammonia.)

This manual is not intended to be a specification manual; it often refers the reader to technical manuals and other sources for more information on the topics discussed. Other sources include manufacturers and distributors of ammonia and technical literature on design, operation, and loss prevention in facilities that handle toxic chemicals.

1.3 USES OF ANHYDROUS AMMONIA

Anhydrous ammonia (NH_3) is a significant commodity chemical, produced by the reaction of hydrogen and nitrogen over a catalyst. The dominant use of this chemical is in the fertilizer industry, which accounts for nearly 80% of all ammonia produced (1). The primary industrial uses of ammonia are as a raw material in the manufacture of nitric acid, as a reactant with nitric acid in the production of explosives, and in the fibers and plastics industry in the production of a number of commercially important synthetic materials. Ammonia has other uses in a wide variety of industries, including neutralization (especially the treatment of acidic wastes), extraction processes, refrigeration, and flue gas scrubbing.

Numerous references in the technical literature offer information on the manufacture and uses of anhydrous ammonia. In the SCAQMD, anhydrous ammonia does not seem to be manufactured by conventional processes for commercial sale. However, it is produced in one specialty process developed for the treatment of contaminated water in a petroleum refinery. Limited survey data indicate that anhydrous ammonia is used or produced in the following processes in the SCAQMD (2):

- A patented process actually called the "waste water treatment" or "WWT" process;

- Manufacture of resins;
- Refrigeration;
- Neutralization of acidic waste streams;
- Preparation of ammonium thiosulfate;
- Reduction of NO_x emissions; and
- Repackaging.

There may be other uses for anhydrous ammonia that were not identified in the available survey data.

1.4 ORGANIZATION OF THE MANUAL

The five sections of this manual discuss the relevant issues associated with the prevention of an accidental release of anhydrous ammonia to the atmosphere. Section 2 discusses the physical, chemical, and toxicological properties of ammonia. Section 3 describes the types of facilities that use ammonia in the SCAQMD, and process hazards associated with these facilities. Hazard prevention and control are discussed in Section 4, as are the costs of example storage and process facilities that reflect different levels of control. Section 5 contains references. Appendix A is a glossary of key technical terms that might not be familiar to all users of the manual, and Appendix B presents selected conversion factors between metric (SI) and English measurement units.

SECTION 2
CHEMICAL CHARACTERISTICS

This section describes the physical, chemical and toxicological properties of anhydrous ammonia as they relate to accidental release hazards.

2.1 PHYSICAL PROPERTIES

At atmospheric temperatures and pressures, anhydrous ammonia is a pungent, colorless gas that may easily be compressed or cooled to a colorless liquid. Table 2-1 shows the more important physical and chemical properties of ammonia.

Pure liquid ammonia is lighter than water, and pure gaseous ammonia is lighter than air. A cloud of pure ammonia gas will be buoyant and rise into the atmosphere; however, depending on the pressure and temperature, air-ammonia mixtures denser than air may also be formed. This can occur when evaporating ammonia cools itself and the surrounding air. For example, air that is adiabatically saturated with ammonia (6.1 wt%) has a density 1.35 times that of air at ambient conditions (3). A saturated air-ammonia mixture, therefore, may remain close to the ground and not disperse very readily. Water vapor may also condense out of an air-ammonia mixture from the cooling effect of evaporating ammonia, causing fog. Because of the higher specific gravity of the cooled air, this fog could spread laterally over the ground (3). Regardless of the temperature and pressure, all air-ammonia mixtures containing more than 45 wt% ammonia are lighter than air (3).

Since liquid anhydrous ammonia has a large coefficient of expansion, an overpressurization hazard exists if storage vessels have insufficient expansion space or if pipelines full of liquid ammonia are sealed on both ends. In these situations, thermal expansion of the liquid with an increase in temperature can result in containment failure from the hydrostatic pressure exerted by the liquid.

TABLE 2-1. PHYSICAL PROPERTIES OF ANHYDROUS AMMONIA

		Reference
CAS Registry Number	07664-41-7	
Chemical Formula	NH_3	
Molecular Weight	17.03	
Normal Boiling Point	-28.17 °F @ 14.7 psia	1
Melting Point	-107.93 °F	1
Liquid Specific Gravity (H_2O=1)	0.6815 @ -27.7 °F	1
Vapor Specific Gravity (air=1)	0.5970 @ 32 °F	1
Vapor Pressure	128.8 psia @ 70 °F	1
Vapor Pressure Equation		4

$$\log Pv = A - \frac{B}{T+C}$$

where: Pv = vapor pressure, mm Hg
T = temperature, °C
A = 7.36050, a constant
B = 926.132, a constant
C = 240.17, a constant

Liquid Viscosity	0.255 cp @ -33.5 °C		4
Solubility in Water at 1 atm, wt. %	32 °F	42.8	5
	50 °F	33.1	
	68 °F	23.4	
	86 °F	14.1	
Specific Heat at Constant Volume (vapor)	0.38 Btu/(lb-°F) @ 32 °F		6

(Continued)

TABLE 2-1 (Continued)

		Reference
Specific Heat at Constant Pressure (vapor)	0.5 Btu/(lb-°F) @ 32 °F	6
Specific Heat at Constant Pressure (liquid)	1.10 Btu/(lb-°F) @ 32 °F	6
Latent Heat of Vaporization	588.2 Btu/lb @ -27.7 °F	1
Liquid Surface Tension	23.4 dynes/cm @ 52 °F	7
Average coefficient of Thermal Expansion at Constant Volume, 0-60°F	0.00377/°F	6

Additional properties useful in determining other properties from physical property correlations:

Critical Temperature	270.32 °F	1
Critical Pressure	1639.1 psia	1
Critical Density	14.66 lb/ft^3	6

The flammability of ammonia in air at atmospheric pressure ranges from 16% to 25% ammonia by volume, while in oxygen the range is from 15% to 79% by volume (4). Increasing the temperature and pressure of the ammonia increases the flammability range. Although the minimum ignition temperature for a mixture within the flammability limits is relatively high at 1562°F (8), ammonia can burn or explode under some conditions, such as a large and intense source of ignition combined with a high concentration of ammonia gas (9). If oil is present, or if ammonia is mixed with other flammable substances, the fire hazard will also increase. It has been reported that the presence of iron appreciably decreases the ignition temperature (9).

Water readily absorbs ammonia to make ammonia liquor (ammonium hydroxide or aqua ammonia). The dissolution of ammonia in water is accompanied by relatively large heats of solution. Approximately 938 Btu of heat is evolved when 2.2 lb of ammonia gas is dissolved in water (5). The solubility of ammonia in water at various temperatures is given in Table 2-1.

2.2 CHEMICAL PROPERTIES AND REACTIVITY

Pure ammonia is a very stable compound under normal conditions; even slight dissociation to hydrogen and nitrogen does not occur at atmospheric pressure until temperatures of 840-930°F are reached (8). The products of complete combustion of ammonia (nitrogen and water) are neither toxic nor hazardous.

Ammonia is a highly reactive chemical, forming ammonium salts with inorganic and organic acids. Three major fertilizers are ammonium nitrate, ammonium sulfate, and ammonium phosphate. Ammonia reacts with chlorine in dilute solution to give chloramines, an important reaction in water purification (5). Another important industrial reaction is the preparation of ammonium carbamate from ammonia and carbon dioxide, which decomposes to give urea and water (5). The alkaline characteristics of ammonia make it useful for neutralizing acidic waste streams in a number of industries.

It has been reported that gold, silver, and mercury are capable of reacting with ammonia to form explosive compounds (1). Other explosive materials that can be formed include metal hydrazides, which are produced from the reaction of alkali metals and liquid ammonia. Acetylides, which are highly explosive in the dry state, are formed in the presence of ammonia solutions of copper, mercury or silver salts (1).

Most common metals do not react with dry ammonia. However, when mixed with small amounts water or water vapor, ammonia will vigorously attack copper, silver, zinc, and many alloys, especially those containing copper (10).

2.3 TOXICOLOGICAL AND HEALTH EFFECTS

Depending on the concentration, the effects of exposure to ammonia gas range from mild irritation to severe corrosion of sensitive membranes of the eyes, nose, throat, and lungs (5). Because of the high solubility of ammonia in water, it is particularly irritating to moist skin surfaces. A concentration of 500 ppm has been designated as the IDLH concentration (Immediately Dangerous to Life and Health), which is based on a 30-minute exposure. Table 2-2 summarizes some of the relevant exposure limits for ammonia gas (11).

Table 2-3 summarizes the predicted human health effects from increasing concentrations of ammonia gas. Because the pungent odor of ammonia is immediately recognizable at low concentrations, it is unlikely that any individual would become overexposed unknowingly. Ammonia is not a cumulative metabolic poison; ammonium ions are actually important constituents of living systems. However, inhalation of high levels of ammonia gas may have fatal consequences because of the spasm, inflammation and edema of the larynx and bronchi, chemical pneumonitis and pulmonary edema (12). Exposure of the eyes to high concentrations may result in ulceration of the conjunctiva and cornea and destruction of all ocular tissues (12).

Contact of the skin with liquid ammonia may cause freezing of the tissue, since liquid ammonia vaporizes rapidly when released to the atmosphere and will absorb heat from any substance it contacts. If the skin is moist, it may also cause severe burns from the caustic action of the ammonium hydroxide produced.

TABLE 2-2. EXPOSURE LIMITS FOR ANHYDROUS AMMONIA

Exposure Limit	Concentration (ppm)	Description	Reference
IDLH	500	The concentration defined as posing an immediate danger to life and health (i.e., causes irreversible toxic effects for a 30-minute exposure).	11
PEL	50	A time-weighted 8-hour exposure to this concentration as set by the Occupational Safety and Health Administration (OSHA), should result in no adverse effects for the average worker.	11
LC_{LO}	30,000	This concentration is the lowest published lethal concentration for a human over a 5-minute exposure.	11
TC_{LO}	20	This concentration is the lowest published concentration causing toxic effects (irritation).	11

TABLE 2-3. PREDICTED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS OF ANHYDROUS AMMONIA

ppm	Effect
5	Least perceptible odor
20-50	Readily detectable odor
40	A few individuals may suffer slight eye irritation
100	Noticeable irritation of eyes and nasal passages after a few minutes exposure
150-200	General discomfort and eye tearing; no lasting effect from short exposure
400	Severe irritation of the throat, nasal passages, and upper respiratory tract
700	Severe eye irritation; no permanent effect if the exposure is limited to less than 1/2 hour
1700	Serious coughing, bronchial spasms, burning and blistering of the skin; less than 1/2 hour of exposure may be fatal
5000-10000	Serious edema, strangulation, asphyxia, rapidly fatal
10000	Immediately fatal

Source: Adapted from references 1 and 5

SECTION 3
FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This section briefly describes the uses of anhydrous ammonia in the SCAQMD and highlights major process hazards related to accidental releases. The discussion addresses processing, repackaging, and storage and transfer as separate topics. Preventive measures associated with these hazards are discussed in Section 4.

3.1 PROCESSING

Limited survey data show that anhydrous ammonia is used for a variety of purposes in the SCAQMD. In the petroleum industry it may be used as a solvent, a refrigerant, a corrosion inhibitor, and as a neutralizer of the acidic constituents of oil. In at least one refinery it is recovered as a salable product from sour water. In the paint and plastic industries, ammonia is a raw material in the production of various resins used in the manufacture of many important synthetic materials. Ammonia has many applications in the SCAQMD as a refrigerant and as a neutralizing agent of acidic waste streams, as found in lead-acid battery manufacturing installations. Ammonia may also be used as a reducing agent in the removal of NO_x compounds from flue gas, in the production of ammonium thiosulfate, and in the preparation of ammonium hydroxide, which is itself a raw material in the manufacture of many specialty chemicals, including nitrogen-containing surface active agents.

3.1.1 Recovery of Ammonia from Waste Water Treatment (13,14)

Waste waters from several petroleum refining processes contain appreciable quantities of ammonia: typical concentrations reported in the literature range from 3% to 10% by weight. The "WWT" Process, a patented process for treating these refinery wastes, recovers high-purity ammonia and hydrogen

sulfide and clean water suitable for reuse or for discharge. The larger WWT units produce more than 50 tons of anhydrous ammonia a day (13).

A typical WWT process arrangement is shown in Figure 3-1. The feed consists of sour water from a degassing unit in which dissolved hydrogen, methane, and other light hydrocarbons are removed. The feed is pumped through a feed heater into a reboiler stripper column from which the hydrogen sulfide is stripped overhead while the ammonia and water are removed as the bottoms product. The overhead product is high purity hydrogen sulfide that contains negligible ammonia. The bottoms product goes directly to a second reboiler stripper column. The bottoms from this column is "clean" water (typically <50 ppm ammonia and <5 ppm H_2S) suitable for many in-plant reuse needs, while the overhead product is ammonia with small amounts of hydrogen sulfide and water. These constituents are removed in the ammonia purification section, which consists of one or more scrubbing stages, depending on the desired purity. The ammonia product is then compressed and condensed to salable anhydrous liquid ammonia. Alternatively, the ammonia product can be produced as high-purity aqueous ammonia solution, eliminating the need for an ammonia compressor. Because the ammonia is handled in solution, the production of aqueous ammonia may be less hazardous than the production of anhydrous ammonia. If there is no immediate use for the ammonia recovered from the second stripper, it can be incinerated in a process furnace or special incinerator.

The hazards that may lead to a large release of ammonia liquid or gas involve the latter portion of the process, where ammonia is present in relatively pure form. This section of the process begins with the overhead product from the second stripper and ends with the final ammonia product storage. Included are the ammonia stripper and condenser; one or more H_2S scrubbers; product compressors, condensers and storage facilities; and associated piping and instrumentation. Process upsets specific to the WWT Process that may lead to a large release of anhydrous ammonia include:

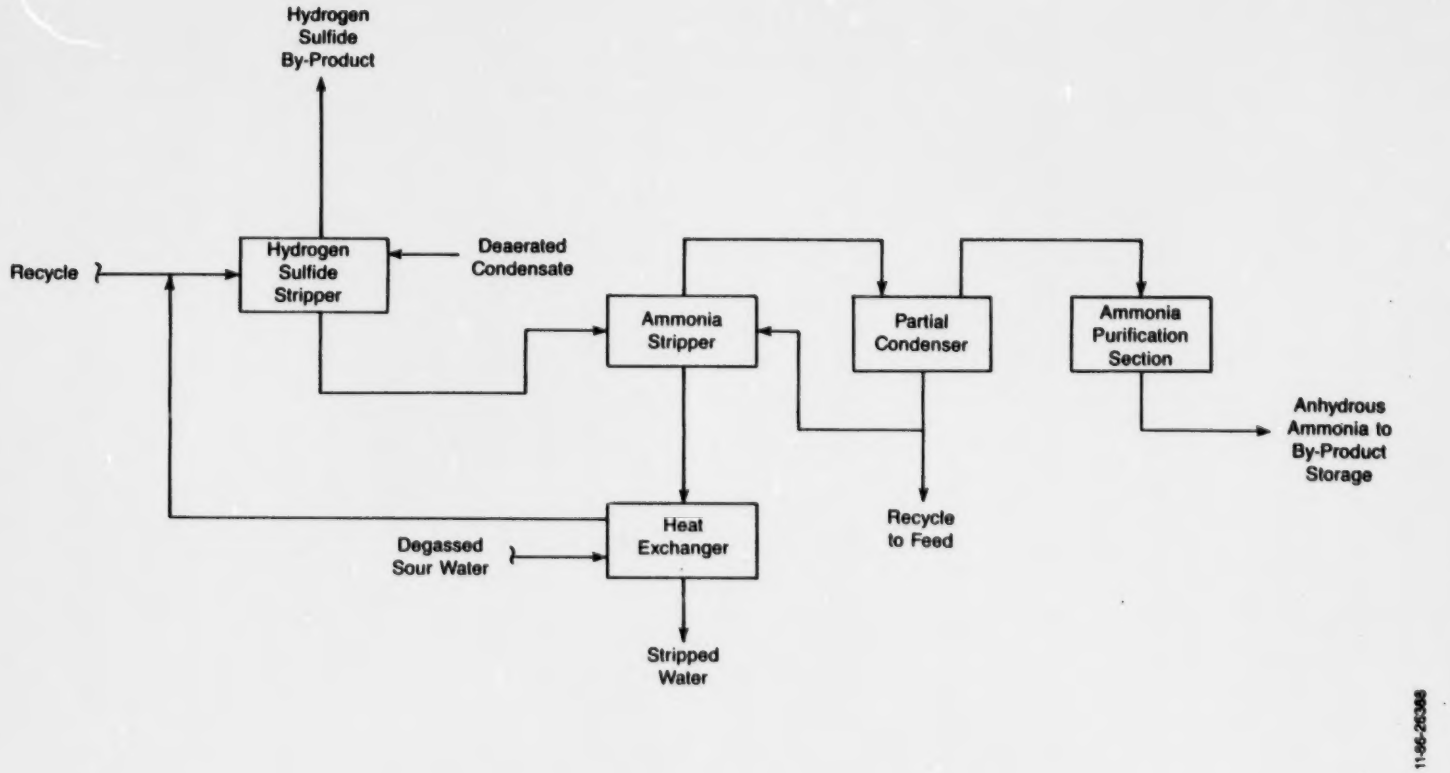

Figure 3-1. Conceptual diagram of "WWT" waste water treatment process.

- Overheating of the ammonia stripper from excess heat to the ammonia stripper reboiler or a sudden decrease in ammonia feed; and

- Overheating of the ammonia condensers from a loss of cooling water.

These process upsets could result in equipment failure from overpressurization. The other high hazard area in the WWT process is the ammonia compressor after the ammonia purification section. Additional hazards associated with the storage and transfer of anhydrous ammonia are discussed in Section 3.3; general causes of equipment failure are discussed in Section 3.4.

3.1.2 The Use of Ammonia in the Production of Resins (15,16,17)

In the SCAQMD, anhydrous ammonia is used indirectly as a raw material in the production of a variety of resins, which have numerous uses in the textile, coating, and plastics industries. Large quantities of ammonia, generally in the form of ammonia derivatives, are consumed in their manufacture. The greatest amounts go to the production of amino, acrylic, and polyamide (nylon) resins, polyurethanes, and linear polyesters (15).

Anhydrous ammonia is used directly as a reactant to produce acrylonitrile, which is a raw material for acrylic resins. The process, shown schematically in Figure 3-2, involves reacting a gaseous mixture of propylene, ammonia, and air in a ratio of 1.4:1.4:10 in the presence of a catalyst. The three reactants are fed to a fluidized bed reactor operating at a temperature of 750-950°F and 5-30 psig pressure. The reactor effluent is scrubbed in a countercurrent absorber, and the organic materials are recovered from the absorber water by distillation. Hydrogen cyanide, water, light ends, and high boiling impurities are removed from the crude acrylonitrile by fractionation to produce specification acrylonitrile product. Because the conversion obtained on a once-through basis is high, no separation or recycling of unreacted raw materials is necessary. However, in another commercial process

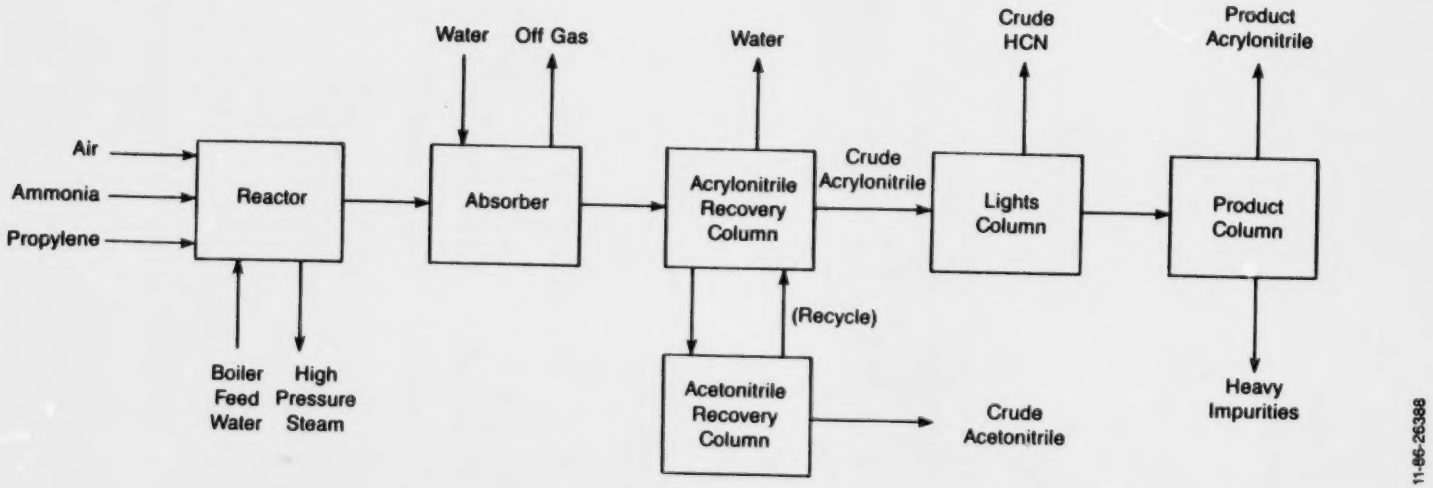

Figure 3-2. Conceptual diagram of typical acrylonitrile process.

that does not have a high conversion, the unreacted ammonia is absorbed by a countercurrent flow of aqueous sulfuric acid to produce ammonium sulfate solution (16).

Hazards that may lead to a large release of anhydrous ammonia in the acrylonitrile production process involve the portions of the process where ammonia is present in relatively pure form. Because no ammonia recovery is required, this only includes the section between the storage (feed) tank and the catalytic reactor. This section contains the storage tank, the ammonia vaporizer, feed preheater, piping to the reactor, a flow controller, and various other instrumentation. Possible causes of a hazardous release from any of these components are discussed in Sections 3.3 and 3.4. Process upsets, e.g. overheating from a loss of cooling water, are unlikely to lead to a large release of ammonia unless coupled with another event such as the loss of ammonia feed control. In the event of a reactor failure, this situation would allow excess ammonia to vent to the atmosphere.

3.1.3 The Use of Ammonia as a Refrigerant (6,18)

One of the predominant uses of ammonia in the SCAQMD is as a refrigerant. Because of its toxic properties, ammonia is primarily used for industrial applications where other systems are not technically or economically feasible.

There are two basic types of refrigeration systems: absorption and vapor compression. While some absorption systems employ ammonia-water solutions as the refrigerant, pure, anhydrous ammonia is only used in vapor compression systems. These systems vary from simple single-stage refrigeration cycles to complex multistage compound or cascade cycles, depending on the application.

Figure 3-3 shows the basic vapor compression refrigeration cycle for a single-stage system. The four basic components are the compressor, condenser, expansion valve, and evaporator. High pressure liquid ammonia flows from the

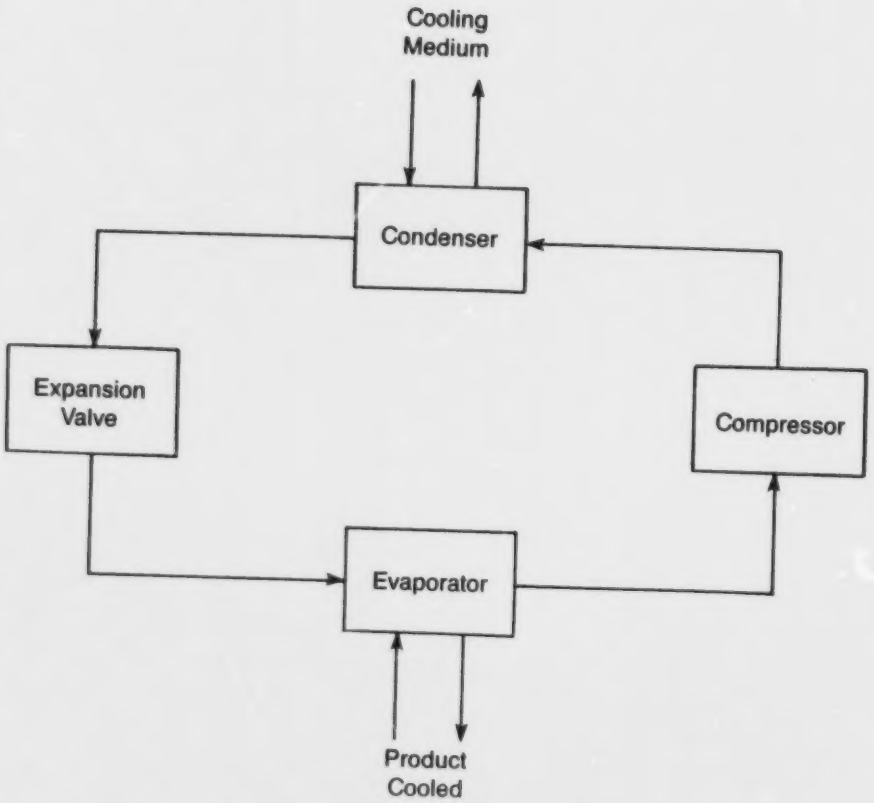

Figure 3-3. Basic vapor compression refrigeration cycle.

condenser receiver through an expansion valve to the evaporator. Here, heat is absorbed from the fluid to be cooled, and the ammonia boils. The gaseous ammonia is then compressed to a temperature and pressure at which the superheated vapor can be condensed by the cooling media available for use in the condenser. The refrigeration cycle thus involves two pressures, high and low, to enable a continuous process that produces the desired cooling effect.

Possible causes of a hazardous release from an ammonia refrigeration system include the following:

- Overpressurization, and
- Equipment failure.

Failure of the refrigeration compressor stops circulation of the refrigerant through the evaporator. If the flow of the fluid being cooled is not stopped, the pressure in the evaporator will rapidly rise and cause the relief valves to open. If these valves are not vented to a closed system, ammonia will be released to the atmosphere. A tube failure in a refrigerant heat exchanger would also cause a rapid pressure rise in the refrigeration system and opening of the relief valves.*

Catastrophic equipment failure could result in a large release of ammonia liquid and/or gas. Because refrigeration systems operate at greater than atmospheric pressure, ammonia will quickly escape from the source of a release.

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*A similar situation can occur if cooling water to the condenser is lost. Relief valves on the condenser would open, if the cooling is not restored in time to prevent a significant rise in pressure.

The primary cause of refrigeration equipment problems is lack of adequate precautions taken during the design, construction and installation of the system (18). The components of a refrigeration system that are especially vulnerable to damage from start-up procedures and process upsets include machinery with moving parts such as pumps and compressors. Abnormally high process temperatures may occur either during startup or process upsets. Provision must be made for this possibility, for it can cause damaging thermal stresses on refrigeration components and excessive boiling rates in evaporators, causing liquid to carry over and damage the compressor.

The system must be kept internally clean during installation because ammonia is a powerful solvent, and dirt, scale, sand, or moisture remaining in the pipes, valves and fittings will be swept along with the suction gas to the compressor, where it is potentially harmful to the bearings, pistons, cylinder walls, valves and lubricating oil. When a compressor is run for the first time, moving parts are often scratched (18). Although damage is only minor in the beginning, scratches may progress until they seriously affect the operation of the compressor or render it inoperative (18).

3.1.4 Neutralization of Acidic Waste Streams with Ammonia (19)

Several companies in the SCAQMD generate waste streams that are acidic in nature. For example, the sulfuric acid used in lead-acid battery manufacturing processes results in waste streams with a pH of around 2 (19). Regardless of the source, acidic wastes must usually be neutralized before further treatment or discharge, and, because of its alkaline properties, anhydrous ammonia is often used as the neutralizing agent for these wastes.

The neutralization process itself is relatively simple. In most processes, anhydrous ammonia is vaporized through a solenoid valve as it leaves a pressurized storage tank. The gaseous ammonia flows through carbon steel piping to a neutralization drum, pit, or tank, where it is sparged into the waste solution. The ammonia may be piped directly into the bottom of the tank

or sent through a vertical feed pipe that is immersed in the solution. The quantity of ammonia fed is automatically controlled by either wastewater flowrate or pH.

Hazards associated with the neutralization process primarily involve the ammonia storage system. The only other part of the process where ammonia is present in nearly pure form is the feed system. However, if a failure in this system caused too much or too little ammonia to be fed, it would probably not result in a large release of anhydrous ammonia. A slight overpressurization potential would exist if the neutralization tank were a closed system without a pressure relief device or if it had insufficient relief piping volume to handle any excess gas not absorbed in solution. However, because ammonia is so soluble in water, it would take a rather large quantity to saturate an aqueous waste stream.

For neutralization systems, suitable materials of construction must be used for the tank and for any ammonia piping that comes into contact with the waste solution. Improper construction materials may lead to corrosion and possible equipment failure. The type of container used, as well as the materials of construction, will depend on the characteristics of the waste. A corrosion hazard also exists if precautions are not taken to prevent backflow of the waste into the carbon steel ammonia piping.

3.1.5 The Preparation of Ammonium Thiosulfate (20,21)

Ammonium thiosulfate is used as a photographic fixing solution and in some agricultural applications. Although this chemical is manufactured in several different ways, the raw materials required for its preparation are the same: ammonia, sulfur dioxide, water, and elemental sulfur.

Figure 3-4 is a block diagram of a typical ammonium thiosulfate process. Ammonia, SO_2, and sulfur are fed to the reaction vessel with a recycle stream containing ammonium bisulfite, sulfur, and water. The fresh ammonia and SO_2

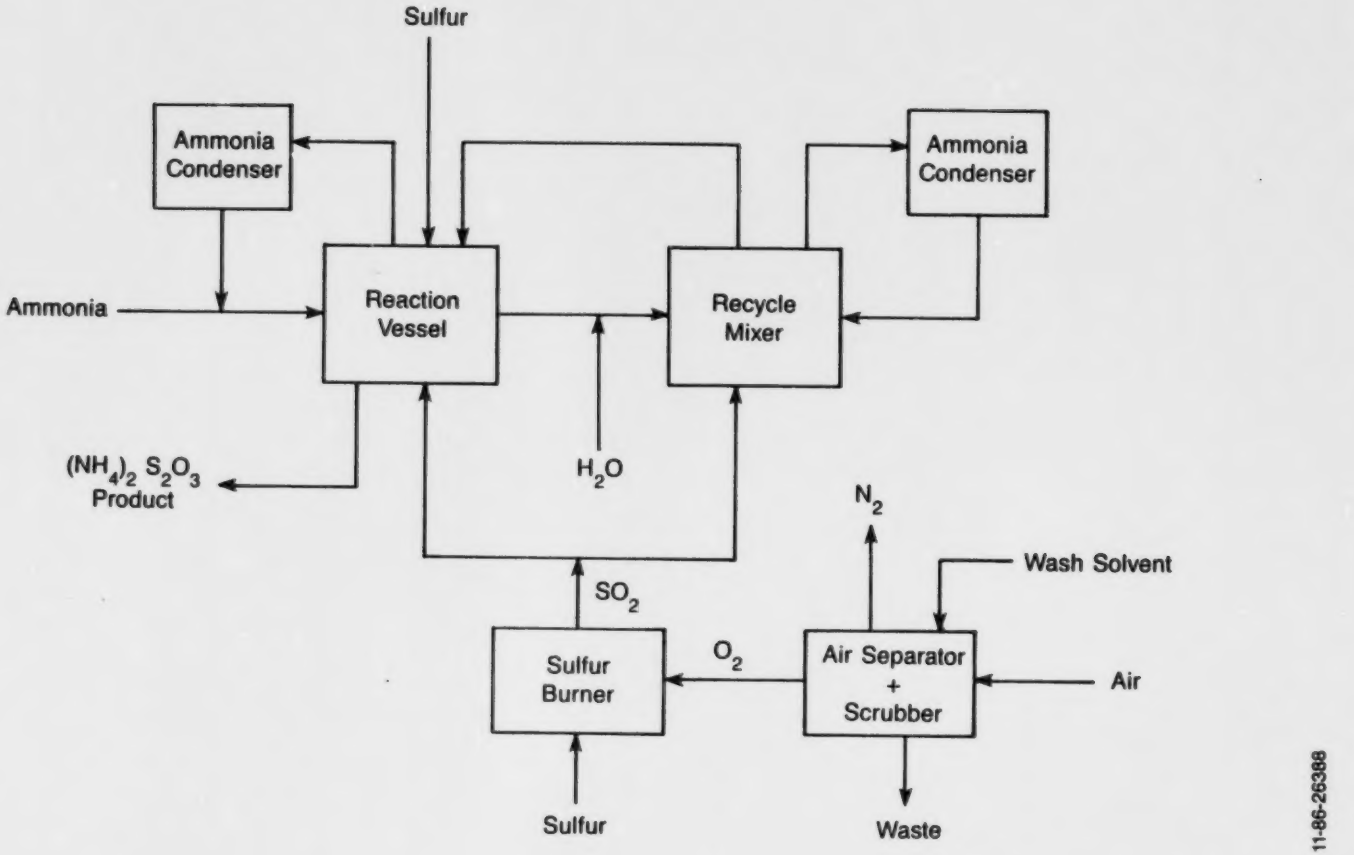

Figure 3-4. Conceptual diagram of typical ammonium thiosulfate process.

combine to form ammonium bisulfite, and this reacts with excess ammonia and sulfur to form primarily ammonium thiosulfate and lesser amounts of ammonium sulfite and ammonium sulfate. The reaction products are not soluble and precipitate out, settling in the bottom of the vessel. From there they may be removed continuously or by periodic scraping. Ammonia and water are removed from the ammonium thiosulfate by drying; the vapors are condensed and recycled back to the system if desired. Sulfur can be removed by washing with ammonia or carbon bisulfide or be left in for fertilizer applications. Ammonia vapors from the vaporization of excess ammonia in the reaction vessel may be taken overhead, condensed, and recycled to the reactor. Water and sulfur dioxide are added to the effluent before it is recycled to the reactor. Ammonia may also be recovered from the vapor leaving the recycle mixing tank. Figure 3-4 shows sulfur dioxide being prepared by combusting sulfur with oxygen, but in practice this chemical can be supplied from any convenient source.

The process just described is only one of several possible methods for producing ammonium thiosulfate. However, the potential hazards arising from the use of ammonia as a reactant will be general to most of the processes for the manufacture of this chemical. Ammonia may also be present in pure or nearly pure form in overhead vapor recovery operations, which involve the compression and condensation of ammonia. Potential causes of failure of these components that may lead to a large release of anhydrous ammonia are not unique to this process and are discussed in Section 3.4.

3.1.6 The Reduction of NO_x Emissions with Ammonia (22)

Ammonia is used in the Selective Catalytic Reduction (SCR) process to reduce nitrogen oxide compounds contained in flue gas. Figure 3-5 shows a schematic of the SCR process, in which gaseous ammonia diluted with either air or steam is injected through a grid system into the flue gas stream upstream of the SCR catalyst. The ammonia/flue gas mixture then enters the catalyst bed, where the ammonia reduces NO_x to N_2 in the presence of oxygen.

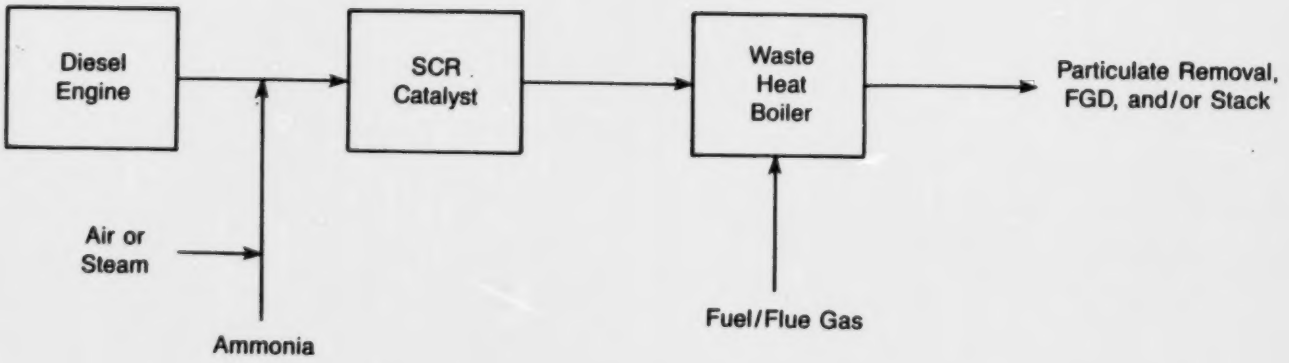

Figure 3-5. Schematic of selective catalytic reduction (SCR) process.

The primary process hazards that may lead to the release of a significant quantity of pure ammonia involve the ammonia storage and feed systems. Hazards associated with the bulk storage of ammonia are discussed in Section 3.3. Potential hazards associated with the feed system are not unique to this process and are discussed in Section 3.4. The only other possible hazard involves a damaged or poisoned catalyst, in which case the unreacted ammonia would presumably pass through the system to discharge. Potential poisons include ammonium sulfates and bisulfates, which may be formed if the operating temperature falls below the optimum range of 590°F to 750°F.

SCR systems generate essentially no liquid or solid wastes that may be considered hazardous. Under normal operation, the ammonia fed to the catalytic converter is destroyed in the reduction process. The concentration of residual ammonia is only 10-15 ppm, which does not exceed the federal standards for ammonia vapor. However, if an excess amount of ammonia were injected into the flue gas, a breakthrough of ammonia into the equipment downstream would result, which could lead to a greater concentration of residual ammonia in the discharge gas.

3.2 REPACKAGING (23)

Anhydrous ammonia is repackaged in the SCAQMD for resale and further use. Repackaging involves a number of procedures which vary, depending on whether liquid ammonia is being transferred from tank cars into tank trucks, or from tank cars, trucks, or bulk storage into cylinders or other portable containers.

Filling operations may be carried out by transferring ammonia directly from the tank car or truck to the receiving container. However, since demurrage begins to accrue after a short period of time, most repackagers first transfer the ammonia to bulk (pressurized) storage before filling the smaller containers. Filling can be accomplished with a compressor or vapor pump by reducing the pressure within the container being filled and at the

same time increasing the pressure within the storage tank being emptied. Filling can also be accomplished by means of a liquid pump. Compressed air should never be used to cause a flow of liquid ammonia, because oxygen contamination in a storage vessel causes stress corrosion cracking in certain carbon steels. During the filling operation the receiving vessels are mounted on scales to determine when they have been filled with the correct amount of ammonia. Some repackagers reweigh the vessels on a second scale to verify that the measurements made with the first scale were accurate.

Potential hazards in repackaging operations include the following:

- Contamination, such as with oxygen (latent hazard);
- Overpressurization of the storage vessel; and
- Overfilling of the receiving vessel.

Stress corrosion cracking of certain carbon steels is caused by oxygen contamination, a hazard discussed in more detail in Section 3.3. Contamination with other materials could result in potentially violent reactions. Accidental overpressure of the storage tank could result in a release of ammonia from the pressure relief valve if it is not vented to a closed system. Overfilling could cause a release from a rupture in the piping or the receiving vessel from a pressure buildup. A latent hazard also exists in an overfilled vessel that goes undetected and leaves the repackaging facility.

Equipment used in repackaging operations should be constructed from materials compatible with ammonia. Suitable materials of construction for ammonia service are discussed in Section 4. Other potential causes of a release include leaks in the connecting piping as a result of corrosion or loose joint-pipe connections, clogging of vapor or liquid pipes leading to overpressure, and human error.

3.3 STORAGE AND TRANSFER

All industries that use or handle ammonia in bulk quantities must have appropriate facilities and procedures for its safe storage and transfer. This section identifies potential hazards common to all installations associated with the storage and transfer of anhydrous ammonia. Proper procedures and safety precautions for the control of these hazards for release prevention are discussed in Section 4.

3.3.1 Storage

Liquid ammonia is stored in either refrigerated vessels at atmospheric pressure or in pressure vessels at ambient temperatures. The type of vessel used at a particular installation generally depends on the relative costs of the two systems. However, materials and fabrication constraints place an upper limit on the size of pressure vessels, so that no more than 50,000 gallons of ammonia should be stored in an unrefrigerated tank (5).

Pressurized storage tanks are generally constructed of carbon steel according to the American Society of Mechanical Engineers (ASME) Code for Unfired Pressure Vessels, Section VIII, Division I, and according to the American National Standards Institute (ANSI) Standards for Piping and Fittings (24,25,26,27). Refrigerated storage tanks with a design pressure of less than 15 psig are constructed in accordance with the American Petroleum Institute (API) Standard 620 (28). The maximum amount of ammonia that may be stored, the "filling density", depends on the type of container and ranges from .56 to .58 times the water weight capacity of the container at 60°F (8).

The predominant use of ammonia in the fertilizer industry has made refrigerated storage economically attractive to producers because the fertilizer season is relatively short, and large single-train plants which produce ammonia year-round require large storage terminals during the off season. The quantities of ammonia involved make pressurized storage prohibitively

expensive. In general, pressurized storage containers are used in conjunction with processes that require relatively small quantities of ammonia (less than 40,000 gallons stored). In the SCAQMD, there are no ammonia plants, and therefore no large capacity refrigerated storage terminals. (The ammonia produced by the largest WWT unit is less than one percent of the output of a large ammonia plant.) In addition, survey data indicate that no facilities in the SCAQMD that store anhydrous ammonia use refrigerated storage. For this reason, only the hazards of pressurized storage systems used for liquid anhydrous ammonia are discussed.

The primary hazard associated with the storage of liquid ammonia is failure of a pressurized storage vessel or of its associated piping. The failure may be a result of cracks or defects in the walls of the vessel at normal operating conditions or could result from a buildup of hydrostatic pressure greater than the design pressure. Possible causes of vessel failure include:

- Corrosion;
- Overheating;
- Overfilling; and
- Failure of safety relief devices.

A predominant internal corrosion hazard of ammonia storage tanks is stress corrosion cracking (SCC), which occurs in certain carbon steels and which has been the subject of extensive research over the last thirty years. The effects of SCC are several hundred or more fine cracks invisible to the naked eye which vary in depth from less than a millimeter to the full thickness of the plate (15). It is generally agreed that the primary cause of SCC is oxygen contamination; cracking may be induced in some vessels with an oxygen concentration as low as 1 ppm (29). The cracks always occur in zones

of high stress, usually the weld deposit. Cracking susceptibility increases with the strength of the steel and with temperature. (No SCC has been reported in refrigerated storage vessels; the reason for this seems to be because any oxygen present is removed in the recompression cycle, and not because of low temperature and pressure (29).) Furthermore, while the addition of 0.1 to 0.2 wt% of water has been found to inhibit cracking in the liquid phase, cracking in the vapor phase still may occur (30). If SCC is not detected promptly, a serious corrosion hazard exists that may ultimately lead to complete failure of the vessel. In addition to SCC, an external corrosion hazard exists where storage vessels are in constant contact with dampness or standing water.

An uninsulated storage vessel filled with ammonia at the maximum filling density will become liquid full at a temperature of 130°F (8). Thus, an overheating hazard exists if ammonia is stored in an area located near flammable or incompatible materials, especially if the area is not well ventilated or heavily trafficked. Cylinders or other storage vessels exposed to direct sunlight also pose an overheating hazard.

Storage vessels may be overfilled because of a malfunctioning scale or level-gaging device, or operator error. An overfilled pressurized ammonia storage tank presents a hazard, because the temperature at which the vessel will become liquid full is lowered, creating the possibility of a liquid-full container with an otherwise insignificant increase in temperature. The resulting hydrostatic pressure would cause the pressure relief device to vent ammonia to the atmosphere; if the pressure relief device failed to activate, a catastrophic release could result from vessel rupture.

3.3.2 Transfer from Tank Cars and Trucks

To reduce the risk of a hazardous chemical release, appropriate procedures must be followed when transferring ammonia from tank cars and trucks to storage vessels. Tank cars are generally unloaded by means of a gas

compressor or transfer unit that creates a pressure differential between the storage vessel and the tank car. Tank cars may also be unloaded with a liquid pump. Examples of potential hazards associated with the unloading of tank cars and trucks include the following:

- The pressure in the tank car or truck attains the pressure setting of its relief valve and ammonia vapor is vented to the atmosphere;

- The pressure in the tank car is lowered so much that the tank is subjected to an internal vacuum condition, possibly caused by a subsequent reduction of ambient temperature;

- The vapor or liquid transfer line becomes clogged or the control valve fails closed, resulting in overpressure of the storage vessel;

- Leakage resulting from pipe corrosion or untightness of joint-pipe connections;

- Incompatible contamination in the receiving vessel that could lead to an uncontrolled reaction and overpressure or corrosion of the receiving vessel;

- A malfunctioning level-indicating device on the receiving vessel results in an overflow of the receiving vessel; and

- Human error.

3.3.3 Transfer from Storage Vessels

Another important aspect of the transfer of liquid or vapor ammonia is the discharge of ammonia from a storage container for its designated use in the plant, which is generally accomplished by means of the pressure differential between the container and the receiving vessel or process to which it is flowing.

The practice of manifolding to withdraw liquid ammonia from two or more cylinders simultaneously is hazardous, because under certain temperature conditions the liquid can flow from one cylinder into another cylinder until it is completely filled (1). If the valve of this completely filled cylinder were subsequently closed, any rise in temperature would result in a build-up of hydrostatic pressure that could rupture the cylinder. Because it is possible that the evaporation of ammonia in a cylinder will cause the ammonia to be refrigerated to the point where there is little or no flow of gas, cylinders are also manifolded together to increase total vapor withdrawal rate. Gaseous transfer between cylinders at different temperatures in such an arrangement is likewise hazardous if there is subsequent reliquefaction and isolation of the overfilled container.

Nitrogen or air padding should not be used to promote the flow of ammonia from cylinders or other storage vessels. Hazards include dangerous high pressures because of an increase in the ambient temperature, and oxygen contamination that causes stress corrosion cracking. Furthermore, cylinders should never be warmed with a flame to increase the discharge rates because of possible pressure buildup sufficient to rupture the container. Other methods, such as a warm water bath, should be used with caution to prevent accidental overpressure of the cylinder.

Other potential hazards include:

- Hazardous backflow into the cylinder or into the upper valve chambers of the feed storage vessel;

- Isolation of liquid ammonia in piping between closed valves that could lead to the line bursting from a build-up in hydrostatic pressure and a temperature increase; and

- Failure of piping connections from corrosion, improper materials of construction, or work hardening, or fatigue.

3.3.4 Transporting Ammonia Storage Containers

Another aspect of storage and transfer is the unloading of containers of ammonia from the delivery vehicle or moving them within the plant. In general, potential hazards associated with the transport of ammonia within a closed vessel arise from failure to safely follow proper transfer procedures. Prevention of a hazardous release resulting from human error is discussed in Section 4.5.

3.4 POTENTIAL CAUSES OF RELEASES

The potential for a hazardous release of liquid or gaseous ammonia exists in any type of facility that handles this material. The possible sources of such a release are numerous. Large-scale releases may be caused by leaks or ruptures of large storage vessels (including on-site tank cars) or by failure of process machinery (e.g., pumps or compressors) that maintain a large throughput of ammonia gas or liquid. Smaller releases may occur as a result of ruptured lines, broken gauge glasses, or leaking valves, fittings, flanges, valve packing, or gaskets.

Failures leading to accidental releases may be broadly classified as due to process, equipment, or operational problems. Causes discussed below are

intended to be illustrative, not exhaustive. More detailed discussion of possible causes of accidental releases are planned for other parts of the prevention reference manual series.

3.4.1 Process Causes

Process causes are related to the fundamentals of process chemistry, control, and general operation. Possible process causes of an ammonia release include:

- Loss of ammonia feed control resulting in the formation of ammonia-air mixtures within the flammability range;
- Backflow of process reactants to an ammonia feed tank;
- Excess feeds in any part of a process leading to overfilling or overpressuring equipment or excess feed to a reactor;
- Loss of condenser cooling to distillation units;
- Overheating of reaction vessels and distillation columns; and
- Overpressure in ammonia storage vessels from overheating (fire exposure) or from unrelieved overfilling.

3.4.2 Equipment Causes

Equipment causes of accidental releases result from hardware failures, including:

- Failure of feed control systems from a loss of power, clogged lines, jammed valves, or instrument failure;

- Excessive stress on materials of construction because of improper fabrication, construction, or installation;

- Failure of pressure-relief systems;

- Mechanical fatigue and shock in any equipment (mechanical fatigue could be caused by age, vibration, excessive external loadings, or stress cycling; shock could occur from collisions with moving equipment, such as cranes or other equipment in process or storage areas);

- Thermal fatigue and shock in reaction vessels, heat exchangers, and distillation columns;

- Equipment constructed of high alloys, especially high strength alloys selected to reduce the weight of major process equipment that might be especially sensitive to corrosion or severe operating conditions;

- Brittle fracture in low-temperature equipment subjected to large temperature swings, or creep failure that might occur in equipment previously subjected to a fire; and

- All forms of corrosion, including stress corrosion cracking from oxygen contamination; pipe connections that have slowly corroded because of contaminants entering the system when cylinders are switched, and external corrosion from exposure to precipitation or constant dampness.

3.4.3 Operational Causes

Operational causes of accidental releases result from the use of incorrect procedures or human error, including:

- Overfilled storage vessels;
- Improper process control system operation;
- Errors in loading and unloading procedures;
- Poor quality control; replacement parts that do not meet system specifications;
- Inadequate maintenance in general, but especially on pressure relief systems and other preventive and protective devices; and
- Lack of inspection and non-destructive testing of vessels and piping to detect corrosion weakening.

SECTION 4
HAZARDS PREVENTION AND CONTROL

4.1 GENERAL CONSIDERATIONS

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices that apply to the design, construction, and operation of facilities where ammonia is stored and used. When developing a thorough release prevention and control plan, the following areas must be considered:

- Process design;
- Physical plant design;
- Operating and maintenance practices; and
- Protective systems.

In each of these areas, specific factors must be considered that could lead to a process upset or equipment failure that could directly or indirectly cause a release of ammonia to the environment. At a minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations. Stricter equipment and procedural specifications should be adhered to if extra protection against a release is considered appropriate.

The following subsections discuss specific aspects of release prevention; more detailed discussions will be found in the manual on control technologies, a companion manual in this series.

4.2 PROCESS DESIGN

Process design involves the fundamental characteristics of the processes that use ammonia, including an evaluation of how deviations from expected process conditions might initiate a series of events that lead to an accidental release. The primary focus is on the basic process chemistry, the variables of flow, pressure, temperature, composition, and quantity. Additional factors may include mixing systems, fire protection, and process control instrumentation. Modifications that enhance process integrity would involve changes in quantities of materials, in process pressure and temperature conditions, in the unit operations and sequence of operations, in process control strategies, and in the instrumentation used.

Table 4-1 shows the relationship between certain specific process design considerations and individual processes described in Section 3 of this manual. This does not mean that other factors should be ignored, nor that proper attention to only those factors in the table will ensure a safe system. However, the considerations listed, and perhaps others, must be properly addressed if a system is to be safe.

The most significant considerations are aimed at preventing overheating and/or overpressurizing systems containing ammonia. Overheating is hazardous because it may lead to overpressure which weakens process equipment and increases the probability of leaks at joints and valves. Wide temperature fluctuations also significantly decrease the lifespan of many construction materials. Overpressure may occur without overheating if flowrate control of both gas and liquid streams is not maintained.

4.3 PHYSICAL PLANT DESIGN

Physical plant design considerations concern equipment, siting and layout, and transfer/transport facilities. Vessels, piping and valves, process machinery, instrumentation, and factors such as location of systems

TABLE 4-1. SOME PROCESS DESIGN CONSIDERATIONS FOR PROCESSES INVOLVING ANHYDROUS AMMONIA

Process Design Consideration	Process or Unit Operation
Contamination (with air especially)	Feed systems, storage tanks, SCR catalyst
Flow control of ammonia feed	All
Temperature sensing and heating media flow control	Distillation and stripping column reboilers
Temperature sensing and cooling medium flow control	Distillation and stripping column condensers
Adequate pressure relief	Storage tanks, reactors, refrigeration condensers, distillation and stripping columns, heat exchangers
Corrosion monitoring	Large inventory equipment such as storage tanks, neutralization equipment
Temperature monitoring	Distillation and stripping column reboilers
Level sensing and control	Storage tanks, reboilers and condensers

and equipment must all be considered. The following subsections cover various aspects of physical plant design, beginning with a discussion of materials of construction.

4.3.1 Equipment

Materials of Construction--

Dry ammonia is noncorrosive to most common metals. However, moist ammonia corrodes copper, tin, zinc, and many alloys, particularly copper alloys. Therefore, only iron or steel, although they decrease the minimum ignition temperature, or other nonreactive material should be used in contact with ammonia (9).

Carbon and carbon-manganese steels are commonly used for various types of equipment in ammonia service. As discussed in Section 3.4.1, one of the primary concerns with ammonia storage is the susceptibility of certain carbon steels to stress corrosion cracking in the presence of small amounts of oxygen. Although it is not possible to specify a particular type of carbon or carbon-manganese steel that will definitely not succumb to stress corrosion cracking, it has been found that low-strength steels (yield less than 50,000 pounds per square inch) are less susceptible to cracking than high-strength steels, and thermal stress relief seems to completely eliminate the mechanism (15).

Piping for ammonia service should be constructed of rigid steel (12). Copper, brass or galvanized fittings should not be used. Unions, valves, gauges, pressure regulators and relief devices having copper, brass or bronze parts are not suitable for ammonia service. Certain aluminum alloys may be used for various components of ammonia systems. Mercury thermometers in ammonia service should be avoided (5).

Metallic and nonmetallic gasket materials, such as compressed asbestos, graphited asbestos, carbon steel or stainless steel spiral-wound asbestos

filled, and aluminum are suitable for ammonia service. Perfluorinated plastic materials and neoprene have also been found suitable if they are fully confined so as to prevent creep or blow out in the event of elevated temperatures (1).

Storage Vessels--

The fact that a large inventory of ammonia contained in storage vessels on site represents one of the most hazardous aspects of a facility that uses or produces this material has been shown by a number of accidental releases from storage tanks over the years. In this section, the different types of ammonia storage vessels and the associated protection devices and safety procedures designed for the prevention of a hazardous release of this material are briefly discussed.

Anhydrous liquid ammonia is stored commercially at full pressure, partially refrigerated, and fully refrigerated in vessels ranging from two-pound cylinders to multi-ton tanks. In general, the quantity of ammonia determines the choice of container, which in turn influences the maximum storage pressure. Storage at ambient temperature (full pressure) is restricted to relatively small vessels, usually uninsulated and cylindrical in shape with rounded ends. The most frequent sizes range from 500 to 45,000 gallons (1). These containers must be designed for pressures of at least 250 psig and constructed in accordance with the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section VIII, Division 1 (24). If the pressure is only partially reduced, the vessel is usually spherical in shape and insulated. The storage pressure is selected to suit the individual requirements of the site process. This type of storage is not as prevalent today as in the past because of the increasing amount of ammonia being stored and transported in the fully refrigerated state.

Full refrigeration of the liquified gas at -27.4°F reduces the pressure essentially to atmospheric. However, a slight positive pressure is necessary to accommodate minor pressure fluctuations and to avoid negative pressure on

the tank, since air must be excluded. Normally, refrigerated vessels are flat-bottomed, insulated, cylindrical tanks that are mounted vertically. Tanks with a design pressure of 15 psig and less must be constructed in accordance with American Petroleum Institute (API) Standard 620 (28), while those with a greater design pressure must be constructed according to the ASME Code cited above.

The most probable causes of failure of an ammonia storage vessel were discussed in Section 3.3; they include corrosion and the buildup of hydrostatic pressure in a liquid-full container caused by overfilling or overheating. Other possible causes of storage tank failure include brittle fracture from overstressing and the use of improper construction materials. This section discusses the safety devices and precautions designed to minimize the chances of an accidental release resulting from one of these causes. Because there is no refrigerated storage of ammonia in the SCAQMD, this discussion will be limited to pressurized storage vessels only.

Precautions should be taken to prevent both internal and external corrosion of ammonia storage vessels. Stress corrosion cracking in ammonia storage vessels is caused by air (oxygen) contamination of the ammonia. The main way of preventing this type of corrosion is by adding at least 0.2% water. This is not an absolute safeguard, however, because cracking can still occur in the areas of the vessel exposed to the vapor phase. Preventive measures that may be taken to reduce the risk of stress corrosion cracking include the following (29):

- Reduce the tensile stress by thermal stress relief of the entire vessel;

- Decrease the residual welding stresses by shotpeening or stress relieving crown plates, leg column plates, and bottom plates in a furnace before commissioning;

- Careful purging when commissioning; and

- Regularly purge the vapor space with an oxygen-free inert gas.

Preventing external corrosion involves good housekeeping and maintenance practices that assure that containers are never in contact with standing water or exposed to continual dampness.

Pressure relief valves and rupture discs are designed to allow a controlled release of overpressurized contents. According to American National Standard (ANSI) K61.1, pressurized ammonia storage containers (with the exception of small cylinders) should be provided with one or more pressure relief valves of the spring-loaded type that are set to discharge at a pressure not exceeding the design pressure of the container. The Compressed Gas Association (CGA) specifies that the maximum discharge rate of the valve should be such that the pressure in the container will not exceed 120% of the design pressure (1). Further provisions recommended by the CGA and ANSI K61.1 include the following (1,8):

- The discharge from pressure relief valves should be directed away from the container upward and unobstructed to the open air.

- Vent pipes should be neither restrictive nor smaller in size than the pressure relief valve outlet connection.

- Vent pipes should have loose-fitting caps to exclude water and debris but must not restrict free discharge of vapor. Suitable provision should also be made for draining condensate that may accumulate.

- Shut-off valves should not be installed between the pressure relief valves and the container unless the arrangement is such that full flow is possible through at least one nonisolated pressure relief valve at the required capacity. (Dual relief valves are usually fitted that can be isolated individually and that are interlocked so that a relief valve can be removed for servicing without losing protection of the vessel (15).)

A cylinder containing less than 165 pounds of ammonia is not required to have a pressure relief device (1). Instead, cylinders are designed to withstand very high pressures, since these containers are generally used indoors where product containment is paramount. Regardless of the higher design pressure, these containers should be protected from fire and direct exposure to the sun, because they are still susceptible to becoming liquid full from an increase in temperature. Without a pressure relief device, overpressure would result in a sudden rupture and complete discharge of the cylinder contents.

In addition to venting provisions, storage vessels should have valve arrangements that allow the vessel to be isolated from the process to which the ammonia is being fed. Backflow of material into the upper valve chambers when the feed valve is shut off at the storage tank must be prevented because of the possibility of corrosion in the feed pipe. Other valve specifications found in ANSI K61.1 require storage tank filling connections to be provided with an approved combination back-pressure check valve and excess flow valve; one double or two single back-pressure check valves; or a positive shut-off valve, in conjunction with either an internal back-pressure valve or an internal excess flow valve (8). Each container should also be equipped with a vapor return valve.

To reduce the risk of overfilling during transfer to a cylinder or bulk storage tank, the vessel is often mounted on a scale that will indicate the weight of fluid in the container at all times. All bulk storage vessels

should also be equipped with a reliable liquid level gauge that allows for quick and accurate readings. The design and installation of an ammonia liquid level gauge should adhere to the requirements given in ANSI K61.1 (8). Most ammonia storage tanks have float-type gauges whereby a float mechanism is magnetically coupled to a pointer that indicates percent of capacity by volume (1). Although this is an accurate method of measuring the level, the equipment is vulnerable to mechanical damage and is often supplemented with an additional measuring device. A differential pressure gauge that measures the static head of the liquid is one possible back-up (15). Each storage container nameplate should include markings indicating the maximum level to which the container may be filled with liquid ammonia between 20°F and 100°F. The percent of the maximum volume of the container that may be filled with liquid ammonia for various temperatures is given in Table 4-2.

Since an overfilled storage vessel is a serious hazard, it is normal for level indicators to be fitted with high-level alarms to warn the operator when the maximum filling level has been reached (15). As a further precaution, a short, vented dip pipe can provide protection from overfilling in the event of failure of the volume or weight measuring device. However, this device will not prevent an overflow of ammonia liquid. Furthermore, it will only work if there is no other outlet from the vapor space and if the line to the vent system has enough capacity. An extra level of protection would be to fit the vessel with a relief device that discharges to an overflow tank or other suitable receiver.

Process and Reaction Vessels--

General hazard control considerations for storage vessels also apply to the design and use of process and reaction vessels. In the latter type of vessels, however, there is a greater degree of hazard, since these containers are often exposed to more severe conditions of temperature and/or pressure than is a regular storage vessel.

Primary considerations for process and reaction vessels include:

TABLE 4-2. MAXIMUM SAFE VOLUME OF LIQUID AMMONIA IN NONREFRIGERATED STORAGE CONTAINERS AT VARIOUS TEMPERATURES

Temperature of Liquid Ammonia in Tank °F	Maximum Safe Volume Liquid Ammonia as a % of Container Water Volume
30	87.3
40	88.3
50	89.5
60	90.7
70	91.8
80	93.0
90	94.4
100	95.7

Source: Reference 1

- Materials of construction;
- Pressure relief devices;
- Temperature control;
- Overflow protection; and
- Foundations and supports.

The foundations and supports for vessels are important design considerations, especially for large storage vessels and tall equipment such as distillation columns. The choice of construction materials is also an important consideration, particularly where low-temperature conditions are encountered. Expert advice should always be sought in the design and procurement of equipment for liquid ammonia duty.

If cooling to a condenser is lost, overpressure may occur; therefore, it is necessary to use pressure relief valves to protect against leaks and ruptures that can result from overpressure. Pressure relief protection is also necessary in the event of a fire.

Distillation and stripping columns present significant release hazards because they may contain large amounts of ammonia in pure form and have a heat input. Since they are often located outdoors, external factors such as ambient temperature fluctuations and wind loadings must be properly accounted for in their design and construction, especially for the support structure.

Piping--

All ammonia piping should be extra heavy (Schedule 80) steel when threaded joints are used (1). However, schedule 40 piping may be used when joints are either welded or joined by flanges. All refrigeration system piping

should conform to ANSI B31.5 - American National Standard for Refrigeration Piping (31). Iron and steel piping, fittings, and valves are suitable for ammonia gas and liquid. Nonmalleable metals, such as cast iron, must not be used for fittings (1). Because low temperature embrittlement is a concern in ammonia systems, material selection must take this into account.

Because liquid ammonia expands with temperature, hydrostatic pressure-bursting of lines must be prevented. This may be accomplished with expansion chambers, which should be located at the highest point of each section that may be closed, trapping liquid ammonia. Construction of these chambers should be in accordance with the ASME Code for Unfired Pressure Vessels, Section VIII (24). An expansion chamber device typically consists of a rupture disc and a receiver chamber that can hold 20-30% of the protected line's capacity. The chamber is equipped with a pressure indicator or alarm switch set to function on disk rupture. Alternatively, a hydrostatic relief valve may be installed in each section of piping in which liquid ammonia can be isolated between shut-off valves.

Following is a list of general guidelines for the safe transport of liquid ammonia in piping systems (8,18):

- Piping systems should have as simple a design as possible and a minimum number of joints and connections; flow should not be restricted by an excessive number of elbows and bends.

- Piping should be at least 7.5 feet above the floor if possible; provision should be made to protect all exposed piping from physical damage that might result from moving machinery, the presence of automobiles or trucks, or any other undue strain.

- In addition to being securely supported, pipes should be sloped with drainage provision at the low points.

- Clips or hangars should not fit too tightly, to allow for thermal expansion of the pipe.

- Piping should be protected from exposure to fire and high temperatures.

- A pressure-reducing regulator should be installed when connecting to lower pressure piping or systems from storage vessels.

- Pipelines should always be emptied when ammonia flow is not required to prevent the possible isolation of liquid ammonia between closed valves.

Valves--

Valves in ammonia service are discussed in a number of references (1,8,18). Several types of valves, including gate, globe, ball, and check configurations, are used in ammonia systems. Construction may be of iron or steel. Copper and copper-bearing materials must not be used for the valve or trim parts, because these materials are attacked by ammonia (when moisture is present.)

It is good practice to locate stop valves in the inlet and outlet lines to all condensers, vessels, evaporators, and long lengths of pipe so they can be isolated in case of leaks and to facilitate pumping out. If globe-type valves are used, they should be installed with the valve stem horizontal to reduce the chance for dirt or scale to lodge on the valve seat or disk (18).

Pressure regulators, solenoid valves, and thermal expansion valves should be flanged for easy assembly and removal. A strainer should be used in front

of self-contained control valves to protect them from pipe construction material and dirt (18). Solenoid valves should be located upright and protected from moisture. A manual opening stem is useful for emergencies.

When ammonia flow is shut off at the feed tank, the piping system between that point and the point of application is filled with vapor. Gradual absorption of the vapor in the process fluid leaves a vacuum that draws ammoniated fluid back into the piping system. This may cause serious problems, especially if the shut-off point is upstream from instruments and other items of equipment. A diaphragm-operated check valve held in a closed position by ammonia pressure may be used to prevent undesired back or reverse flows. If the ammonia pressure falls and pressure on the diaphragm becomes subatmospheric, the valve opens and allows air to flow into the piping system, thus breaking the vacuum that would otherwise cause backflow of the process fluid.

Excess flow valves should be considered for ammonia in vessels, tank cars, and other places where unintentional high liquid discharge rates need to be prevented. If a liquid discharge line is broken, the resulting high flow rate would cause the valve to close off, restricting the escape of ammonia.

The pressure of ammonia gas can be controlled by a pressure reducing and regulating valve of steel construction. The valve should be designed for the range of conditions under which it will be required to operate, taking into account the maximum and minimum flow of ammonia gas, its average temperature, and the average upstream and downstream pressures (1).

Process Machinery--

Process machinery refers to rotating or reciprocating equipment that may be used in the transfer or processing of ammonia. Included in this classification are pumps and compressors that may be used to move liquid or gaseous ammonia where gas pressure padding is insufficient or inappropriate.

Pump--

Any pump used in ammonia service must conform to ANSI/UL 51 - American National Standard for Power-Operated Pumps for Anhydrous Ammonia and LP Gas (32). To ensure that a given pump is suitable for an ammonia service application, the design engineer should obtain information from the pump manufacturer certifying that the pump will perform properly in this application.

Centrifugal pumps are normally used for pumping liquefied ammonia in a fully refrigerated condition (15). Glandless, canned-type or conventional pumps fitted with either a single mechanical seal together with a soft packed auxiliary gland or a double mechanical seal may be used. Canned pumps are generally used indoors or in congested areas. When a glanded pump is used, a mechanical seal is advisable, followed by a soft packed gland (15). The seal pressure should not exceed the manufacturer's recommendations, and the interspace should be vented in a safe manner.

Pumps should be constructed of materials resistant to ammonia at operating temperatures and pressures. Lubricating oil should be resistant to breakdown after contact with ammonia. In some cases, the potential for seal leakage may rule out the use of rotating shaft seals. Some pump types that either isolate the seals from the process stream or eliminate them altogether include canned motor, vertical extended spindle submersible, magnetically-coupled, and diaphragm (6).

Net positive suction head (NPSH) considerations are especially important for ammonia, since the liquid may be pumped near its boiling point. Long suction lines reduce the effective NPSH available, and if the suction lines are very long in relation to the NPSH available, a vapor release vessel should be fitted in the suction line as close to the pump as possible (15). The pump supply tank should have high and low level alarms, and the pump should be interlocked to shut off at low supply level or low discharge pressure.

Centrifugal pumps often have a recycle loop back to the feed container that prevents overheating if the pump is deadheaded (i.e., the discharge valves close.) Positive displacement pumps can be equipped with a constant differential relief valve capable of discharging the entire capacity of the pump into the suction port of the pump to prevent rupture if deadheading occurs. When a positive displacement pump is used to reduce the chance of backflow, such a relief valve could defeat this purpose if the back pressure were high enough. In such a case, the relief valve discharge should be routed somewhere other than to the suction part of the pump. Pumps can also be protected by a differential pressure switch fitted across the pump to trip the motor should a low-pressure condition arise. This could be caused by inadequate priming, by vaporizing in the pump, or by too low a suction head.

Compressors--

Ammonia compressors include reciprocating, centrifugal, liquid-ring rotary, and non-lubricated screw compressors. Usually two-stage reciprocating compressors are used for ammonia service, although rotary compressors are also common and may be preferable if it is necessary to avoid oil contamination (15). Detailed descriptions of the different types of compressors may be found in the technical literature (6).

As with pumps, construction materials must be selected that are compatible with ammonia at the operating conditions. Copper and copper-bearing alloys must be avoided and particular attention paid to the gland arrangement (15). Any ammonia compressor must be designed for at least 250 psig working pressure, except those used for refrigeration service.

A pressure relief valve large enough to discharge the full capacity of the compressor should be installed between the discharge of the compressor and the high pressure shut-off valve. If the crank case is not designed to withstand system pressure, it should also be protected with a suitable pressure relief valve. In addition, a liquid trap should be installed before the compressor suction to prevent entry of liquid into the compressor.

Miscellaneous Equipment--

Pressure Relief Devices— Pressure relief devices for ammonia service should be constructed in accordance with CGA S-1.3 - "Pressure Relief Device Standards - Part 3 - Compressed Gas Storage Containers" (33). All wetted parts of relief valves and rupture disks should be constructed from materials compatible with ammonia at the operating temperature and pressure. For balanced relief valves, the balance seals must also be made of appropriate materials.

Measures should be taken to ensure that process equipment is not isolated from its relief system. To provide continuous pressure relief protection when a device requires maintenance, equipment may be provided with dual relief systems, each sized to provide the total required flow capacity. Stop valves installed between a vessel and its relief device should have a full port area at least equal to that of the pressure relief device inlet. These valves should be locked open or have handles removed when the protected vessel is in use. If the discharge is to be piped to a closed disposal system, the pressure drop caused by the additional piping must be considered and the relief device sized accordingly.

Some aspects of the proper placement and use of pressure relief valves have been discussed earlier in this section in conjunction with storage vessels. Additional guidelines for the correct use of pressure relief valves include the following (8):

- Arrangement should minimize the possibility of tampering with the pressure setting adjustment;

- They should have direct communication with the vapor space of the container;

- The flow capacity should not be restricted by any connection to it on either the upstream or downstream side; and

- Discharge from pressure relief valves should not terminate in or beneath any building.

Rupture disks may be used to protect pressure relief valves from constant contact with the contents of the storage vessel. Rupture disks should not be used in ammonia service, however, where the ruptured disk discharges directly into the atmosphere. If the disk relieves the contents of the container through a spring-loaded pressure relief valve, a small vent should be provided in the chamber between the disk and the valve to prevent any back pressure on the rupture disk. Because operating pressures exceeding 70% of a disk bursting pressure may induce premature failure, a considerable margin should be allowed when sizing rupture disks.

Instrumentation-- For normal applications, all steel pressure gauges graduated from 0-400 psig are recommended for ammonia service (1). For low pressure work, the range for the gauge should be one and one-half times the maximum service pressure.

The most commonly used flowmeter for ammonia gas is the tapered tube, float type (1). For high pressure work the glass tube should be enclosed in a vented shield or, preferably, a steel-armored type. Orifice meters with differential pressure cells may also be used. Mercury manometers should not be used in ammonia service. The quantity of liquid ammonia transferred from one system to another may be measured with positive displacement or turbine meters.

Magnetic or rotary gauges are preferred to gauge glasses (5). Ammonia should never be closed into a gauge glass, since an increase in pressure may break the glass. Glasses should be equipped with excess flow valves to stop

the flow of ammonia if breakage occurs, and they should have automatic self-closing shutoff valves that must be held open to take a reading (5).

4.3.2 Plant Siting and Layout

The siting and layout of a particular ammonia facility is a complex issue that requires careful consideration of numerous factors, including the other processes in the area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects, such as flooding.

The siting of facilities or individual equipment items should reduce personnel exposure, both plant and public, in the event of a release. Since there are also other siting considerations, there may be trade-offs between this requirement and others in a process, some directly safety related. Siting should allow ready ingress or egress in the event of an emergency and yet also take advantage of barriers, either man-made or natural that could reduce the hazards of releases. Large distances between large inventories and sensitive receptors is desirable.

Various techniques available for formally assessing a plant layout should be considered when planning high hazard facilities (34).

The siting and layout of any facility handling ammonia should adhere to the following general guidelines:

- Areas where ammonia hazards exist should have an adequate number of well-marked exits through which personnel can escape quickly if necessary; doors should open outward and lead to unobstructed passageways;

- The plant should be laid out so that there are no confined spaces between equipment; large distances between large inventories and sensitive receptors is desirable;

- Access to platforms above ground level should be by stairway instead of cat ladders, and work areas above ground level should have alternative means of escape;

- The ground under process equipment and storage vessels should be sloped so that fire water and liquid spillages flow away from equipment and into drains;

- Storage facilities should be located in cool, dry, well-ventilated areas, away from heavily trafficked areas and emergency exits; and

- Tank car, tank truck and storage facilities should be located away from sources of heat, fire and explosion.

Because heat causes thermal expansion of liquid ammonia, measures should be taken to situate piping, storage vessels, and other ammonia equipment so that they are not located adjacent to piping containing flammable materials, hot process piping, equipment, steam lines, and other sources of direct or radiant heat. Special consideration should be given to the location of furnaces and other permanent sources of ignition in the plant. Storage should also be situated away from control rooms, offices, utilities, and laboratory areas.

In the event of an emergency, there should be more than one entrance to the facility which is accessible to emergency vehicles and crews. Storage vessel shut-off valves should be readily accessible. Containment for liquid storage tanks can be provided by diking, which reduces evaporation rates while containing the liquid. It is also possible to equip a diked area with drainage to an underground containment sump. This sump would be vented to either a recovery or scrubber system for safe removal. A full containment system in a specially constructed building is another possible option. This type of

secondary containment could be considered for large volume, liquid ammonia storage tanks.

4.3.3 Transfer and Transport Facilities

Transfer and transport facilities where both road vehicles and rail tankers are loaded or unloaded are likely accident areas because of vehicle movement and the intermittent nature of the operations; therefore, special attention should be given to the design of these facilities.

Before unloading, tank vehicles should be securely moored; an interlocked barrier system is commonly used. Tank cars must also be protected on both ends by derailers or on the switch end if located on a dead end siding. Sufficient space should be available to avoid congestion of vehicles or personnel during loading and unloading operations. Vehicles, especially trucks, should be able to move into and out of the area without reversing. High curbs around transfer areas and barriers around equipment should be provided to protect equipment from vehicle collisions.

Correct procedures must be followed when unloading and handling small ammonia storage vessels. Dragging, sliding, or rolling cylinders, even for short distances, is not acceptable. Lifting magnets, slings of rope or chain, or any other device in which the cylinders themselves form a part of the carrier should never be used for transporting cylinders.

4.4 PROTECTION TECHNOLOGIES

This subsection describes two types of protection technologies for containment and neutralization:

- Enclosures,
- Scrubbers, and
- Flares.

4.4.1 Enclosures

Enclosures refer to containment structures that capture any ammonia spilled or vented from storage or process equipment, thereby preventing immediate discharge of the chemical to the environment. The enclosures contain the spilled liquid or gas until it can be transferred to other containment and discharged at a controlled rate that would not be injurious to people or to the environment, or transferred at a controlled rate to water scrubbers for absorption.

Specially designed enclosures for ammonia storage or process equipment do not appear to be in widespread use, since some sources suggest that it is preferable to locate toxic operations in the open air (34). The desirability of enclosure depends partly on the frequency with which personnel must be involved with the equipment. A common design rationale for not having an enclosure where toxic materials are used is to prevent the accumulation of toxic concentrations within enclosed areas. However, if the issue is to provide secondary containment, total enclosure may be appropriate. Enclosures should be equipped with continuous monitoring equipment and alarm, which should sound whenever lethal or flammable concentrations are detected.

Care must be taken when an enclosure is built around pressurized equipment. It would not be practical to design an enclosure to withstand the pressures associated with the sudden release of a pressurized vessel because the pressure created from such a release could cause an enclosure to fail and create an additional hazard. If an enclosure is built around pressurized equipment, it should be equipped with some type of explosion protection, such as rupture plates designed to fail before the entire structure fails.

An enclosure would have a ventilation system designed to draw in air when the building is vented. The bottom section of an enclosure used for stationary storage containers should be liquid tight to retain any liquid ammonia that might be spilled. Enclosures around rail tank cars which are used for

storage do not normally lend themselves easily to effective liquid containment. However, containment can be accomplished if the floor of the enclosure building is excavated several feet below the track level while the tracks are supported at grade in the center.

While the use of enclosures for secondary containment of ammonia spills or releases is not widely used, it might be considered for areas near sensitive receptors.

4.4.2 Scrubbers

Scrubbers are a traditional method for absorbing toxic gases from process streams. These devices can be used for the control of ammonia releases from vents and pressure relief discharges, from process equipment, or from secondary containment enclosures.

Because of its high solubility, ammonia discharges could be absorbed in water in any of several types of scrubbing devices. Types of scrubbers that might be appropriate include spray towers, packed bed scrubbers, and venturis. Other types of special designs might be suitable, but complex internals subject to corrosion do not seem to be advisable.

For any type scrubber selected, a complete system would include the scrubber itself, a liquid feed system, and water makeup equipment. If such a system is used as protection against emergency releases, consideration must be given to how it would be activated in time to respond to an emergency load. One approach used in some process facilities is to maintain a continuous circulation of scrubbing liquor through the system. For many facilities this would not be practical, and the scrubber system might be tied into a trip system to turn it on when needed.

Venturi scrubbers have an advantage where the scrubbing system must be activated by a trip system. Since a venturi scrubber can create its own draw

of vapor by the flow of the scrubbing medium, a trip system need only turn on the flow of liquid to the scrubber rather than turn on the flow of liquid and start up a blower, as would be required in other types of scrubbing systems.

Another approach is the drowning tower, where the ammonia vent is routed to the bottom of a large tank of uncirculating water. The drowning tower does not have the high contact efficiency of the other scrubber types; however, it can provide substantial capacity on demand as long as the back pressure of the hydrostatic head does not create a secondary hazard, by impeding an overpressure relief discharge.

4.4.3 Flares

Flares are devices routinely used in the chemical process industries to burn intermittent or emergency emissions of ammonia waste gases (35). A flare is a section of vertical piping with a specially designed combustion tip. The flare burns the ammonia, forming carbon dioxide and nitrogen oxide. Although ammonia is not usually thought of as a flammable gas it can burn if ignited at a high enough temperature (1,200 °F). Its flammability limits in air are 15.0 to 25.0 % (5). Flares are distinguished from other process combustion devices such as incinerators by their design to handle extreme flow rate variations and their unenclosed combustion zone.

A total flare system consists of collection piping, a seal pot, a liquid knock-out vessel, and the flare itself. Two basic types of flares are elevated flares and enclosed ground flares. The elevated flare is usually designed to handle larger flows than the ground flare, and is more likely to be used for high volume upset or emergency flaring situations. The ground flare is more likely to be used for smaller volume, routine process venting.

Basic design requirements for flares burning ammonia are:

- The ability to operate safely over a wide range of flow rates and varying compositions,
- Have acceptable emissions of radiant heat and noise, and
- Achieve acceptable destruction efficiency for ammonia.

The ability of flares to accommodate large variations in flow rate is an important consideration in using them for protection against accidental ammonia releases. Depending on the size of a flare relative to a potential release, the accidental release flow rate may constitute a large or small fraction of the total flare flow rate and correspondingly could have a significant or relatively minor effect on the instantaneous total flow rate and flare performance.

There are two possible ways a flare system can be used to protect against accidental ammonia releases. The first is to use an existing flare system. The second is to use a dedicated "emergency" system. Whether a dedicated flare or shared flare is used depends on site specific considerations. A shared flare may be advantageous for several reasons. A dedicated flare system for infrequent emergency use may be difficult to safely maintain in full working condition. A shared flare may allow connection to an existing system. With a shared flare, however, design for emergency conditions must ensure that a large release of ammonia does not overwhelm the flare and lead to flame blowout, or that the pressure from the toxic emergency release does not cause a backflow into other process units tied into the flare collection piping.

The primary compositional requirement of flares is that the vented gases are easily ignitable and have adequate heating value to minimize supplementary fuel requirements. Ammonia has a net heating value of 365 Btu/ft^3, which is greater than the minimum required (35). However, without assist gas, approximately 8 percent of the ammonia is released unburned (35). The

fundamental flare design variable is exit velocity. At maximum flow, the flame should not leave the burner tip or be blown out. This is achieved by limiting the exit velocity. Criterion has been recommended by the EPA to ensure 98 percent destruction efficiency of flared chemicals using a steam-assisted flare (36).

Flares can be useful protection against accidental releases of ammonia. However, because of potentially dangerous secondary hazards, their use requires a thorough analysis for each specific application. In essence, a flare system is a pipe transporting flammable gases to a flame at the exit. As long as the flame remains at the end of the pipe, the system operates safely. The flame can enter the pipe if oxygen is present above a certain concentration in the fuel. In a dedicated flare system, the entire collection network would have to be continually purged to prevent the risk of an explosion when a accidental release occurred.

Backpressure in the discharge line for an emergency ammonia release is a concern in discharging to a flare system. Since the flare collection system operates under a positive pressure (above atmospheric), release rates from an emergency relief valve will be less than discharge tot he atmosphere. In some instances, it is conceivable that the slight delay in reducing the pressure in a vessel may cause tank damage. This may be especially important when rupture disks blow. A sudden overpressurization of the flare collection system due to a massive accidental release could damage the pipes or potentially affect the venting of other process units. Table 4-3 summarizes the factors that need to be considered to prevent accidental chemical releases when using a flare system.

4.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a large release of anhydrous ammonia occurs, the first priority is to rescue workers in the immediate vicinity of the accident and evacuate persons from downwind areas. The source of the

TABLE 4-3. IMPORTANT CONSIDERATIONS FOR USING FLARES TO PREVENT ACCIDENTAL CHEMICAL RELEASES

- Maximum flow rate - will it cause a flame blowout?
- Possibility of air, oxygen, or other oxidant entering system?
- Is gas combustible - will it smother the flare?
- Will any reactions occur in collection system?
- Can liquids enter the collection system?
- Will liquids flash and freeze, overload knockout drum or cause rain fire?
- Is back pressure of collection system dangerous to releasing vessel?
- Is releasing vessel gas pressure or temperature dangerous to collection system?
- Will acids or salts enter collection system?
- Will release go to an enclosed ground or elevated flare?
- If toxic is not destroyed, what are the impacts on surrounding community?

release should be determined, and the leak should be plugged to stop the flow if this is possible. This post release mitigation effort requires that the source of the release be accessible to trained plant personnel, and that adequate personnel protection be readily available. Personnel protection includes such items as portable breathing air and chemically resistant protective clothing.

The next primary concern becomes reducing the consequences of the released chemical to the plant and the surrounding community. Reducing the consequences of an accidental release of a hazardous chemical is referred to as mitigation. Mitigation techniques include such measures as physical barriers, water sprays and fogs, and foams. The purpose of a mitigation technique is to divert, limit, or disperse the chemical that has been released to the atmosphere. The mitigation method chosen for a particular chemical will depend on the specific properties of the chemical, including its flammability, toxicity, reactivity, and those properties that determine its dispersion characteristics in the atmosphere.

If a release occurs from a pressurized ammonia storage tank, a quantity of liquid will immediately flash to its atmospheric boiling point and produce a vapor/aerosol cloud of ammonia. The remaining liquid will cool to the normal boiling point of -28°F. Heat transfer from the air and ground will result in further vaporization of the released liquid. Since the ammonia accidentally released from a refrigerated storage tank is already at or below its normal boiling point, a comparable quantity of vapor will not flash off, as with a pressurized release, but heat transfer from the environment will still quickly cause the formation of a vapor cloud. It is therefore desirable to decrease the area available for heat transfer to a liquid spill, which in turn will minimize the rate of evaporation. Mitigation technologies used to reduce the rate of evaporation of a released liquified gas include secondary containment systems such as impounding basins, dikes, and enclosures.

4.5.1 Secondary Containment Systems (8,37,38)

Specific types of containment systems include excavated basins, natural basins, earth, steel, or concrete dikes, and high impounding walls. The type of containment system best suited for a particular facility will depend on the risk associated with an accidental release from that location. The inventory of ammonia and its proximity to other portions of the plant and to the community are primary considerations in the selection. The secondary containment system should be able to contain spills, minimizing damage to the facility and its surroundings and reducing the potential for escalation of the event.

While it is common practice to provide ammonia storage tank installations with an earth or concrete dike to contain the liquid into a manageable pool should a total failure of the main tank occur, the efficacy of a dike in the event of a release from pressurized storage has been questioned, because a sudden loss of pressurized containment tends to result in ejection of all the contents in the form of vapor, or spray, leaving no residual liquid (15). There may, however, be situations where a dike would be appropriate for a pressurized ammonia storage vessel.

A conventional dike is useful when refrigerated storage is involved because the liquid is already at atmospheric pressure and it is assumed that most of the contents of the tank will be contained within the confines of the dike in the event of a release from the tank. ANSI K61.1 requires that one of the following should be provided with any primary refrigerated storage system; it includes no similar provisions for pressurized storage (8):

- An adequate drainage system underlying the storage vessels that terminates in an impounding basin whose capacity is as large as that of the largest tank served; or

- A diked area whose capacity is as large as that of largest tank served.

These measures are designed to prevent accidental discharge of liquid ammonia from spreading to uncontrolled areas.

The most common type of containment system is a low wall earth dike surrounding one or more storage tanks. Generally, no more than three tanks are enclosed within one diked area. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible. Vapor fences may be situated on top of the dikes to provide additional vapor storage capacity. If there is more than one tank in the diked area, the tanks should be situated on berms above the maximum liquid level attainable in the impoundment.

To achieve the required volumetric capacity, dike heights usually range from 3 to 12 feet, depending on the area available. The dike walls should be liquid tight and able to withstand the hydrostatic pressure and temperature of a spill. It may be necessary to construct low wall dikes of low temperature steel or concrete because of adverse soil conditions or other specific requirements. In addition, some experiments have shown that earth dikes should be covered with a layer of clay, asphalt, plastic film, or a similar material impermeable to liquid ammonia (39). Otherwise, the ammonia will percolate into the ground, and the loss of ammonia by evaporation will be greater in the absence of an impermeable layer over the dike.

A low wall dike can effectively contain the liquid portion of an accidental release; however, since a dike also limits access to the tank during a spill, a remote impounding basin may be considered if a relatively large site is available within a reasonable distance of the storage system. With such a system, the flow is directed to the basin by dikes and channels under the storage tanks; these are designed to minimize exposure of the liquid to other tanks and surrounding facilities. The advantages of this type of system are:

- The spilled liquid is removed from the immediate tank area;

- The probability of the spilled liquid causing further damage to the tank, piping, electrical facilities, pumps, and other equipment is reduced;

- The tank area is accessible during the spill; and

- Access to the tank pumps or related piping for regular operation, inspection, or maintenance is not restricted by the impoundment.

The impounding basin may be located to take advantage of the natural topography of the area, thus minimizing additional excavation and diking. A sump can also be provided within the main impounding basin to limit the liquid surface and ground contact areas. Furthermore, the depth of the basin can be increased to provide vapor containment.

Although few authorities for ammonia facilities require them, high wall impoundments may be the best secondary containment choice for selected systems. Circumstances that may warrant their use include limited storage site area, the need to minimize vapor generation rates, and/or the need for the tank to be protected from external hazards. Maximum vapor generation rates will generally be lower for a high wall impoundment than for low wall dikes or remote impoundments because of the reduced surface contact area. These rates can be further reduced with insulation on the wall and floor in the annular space. High impounding walls may be constructed of low-temperature steel, reinforced concrete, or prestressed concrete. A weather shield may be provided between the tank and wall with the annular space remaining open to the atmosphere. The available area surrounding the storage tank will dictate the minimum height of the wall. The walls may be designed with a volumetric capacity greater than that of the tank to provide vapor containment. Increasing the height of the wall also raises the elevation of any released vapor.

One disadvantage of these dikes is that high walls around a tank may hinder routine external observation. Furthermore, the closer the wall is to the tank, the more difficult it becomes to reach the tank for inspection and maintenance. As with low wall dikes, piping should be routed over the wall if possible. The closeness of the wall to the tank may necessitate placement of the pump outside of the wall, in which case the tank outlet (suction) line will have to pass through the wall. In such a situation, a low dike encompassing the pipe penetration and pump may be provided, or a low dike may be placed around the entire wall.

A further type of secondary containment system is one structurally integrated with the primary system and forming a vapor-tight enclosure around the primary container. Such a system may be considered when protection of the primary container and containment of vapor for events not involving foundation or wall penetration failure are of greatest concern. The drawbacks of an integrated system are the greater complexity of the structure, the difficulty of access to certain components, and the fact that complete vapor containment cannot be guaranteed for all potential events.

Provision should be made for draining of rainwater from both impounding basins and diked areas. This will involve sumps and separate drainage pumps, since direct drainage to stormwater sewers would presumably allow any spilled ammonia to follow the same route. Alternately, a sloped rain hood may be used over the diked area, which could also serve to direct the rising vapors to a single release point (38). The ground within the enclosure should be graded so that the spilled liquid will accumulate at one side or in one corner, which will help decrease the area of ground to which the liquid is exposed and from which it may gain heat. In areas where it is critical to minimize vapor generation, surface insulation may be used in the diked area or impoundment to further reduce heat transfer from the environment to the spilled liquid. The floor of an impoundment should be sealed with a clay blanket to prevent the ammonia from seeping into the ground; percolation into the ground causes the

ground to cool more quickly, increasing the vapor generation rate. Absorption of the ammonia into water in the soil would also release additional heat.

4.5.2 Flotation Devices and Foams (39,40,41,42)

Other possible means of reducing the surface area of spilled liquid ammonia include placing impermeable flotation devices on the surface, dilution with water, and applying water-based foams.

Placing a lid over a spilled chemical is a direct way of containing the toxic vapors, with nearly 100 percent efficiency. The floating cover may be continuous or a distribution of light particulates. However, this technique requires that a cover be acquired before the spill occurs and stored until needed, and in all but small spills deployment may be difficult. Furthermore, although particulate covers are potentially effective, cost is a deterrent to their use. Determining what materials are appropriate for an ammonia spill has been the subject of some research (37), but the use of mechanical barriers on an actual spill has not been reported in the literature.

One approach to an ammonia spill is dilution with water, but, because of the high heat of solution, adding pure water would cause a violent boil-off of ammonia. A water-based foam cover is one way of diluting the ammonia with a minimum heat of solution because water is added slowly. While the use of foams for vapor hazard control has been demonstrated for a broad range of volatile chemicals, it is difficult to accurately quantify the benefits of foam systems, because the effects will vary as a function of the chemical spilled, foam type, spill size, and atmospheric conditions. With regard to liquified gases, it has been found that with some materials, foams have a net positive effect, but with others, foams may exaggerate the hazard.

When a foam cover is first applied, an increase in the boil-off rate is usually observed that causes a short-term increase in the downwind ammonia concentration. The initial foam cover may be destroyed by violent boiling, in

which case a second application is necessary. Once a continuous layer is formed, a net positive effect will be achieved in the downwind area (40). The reduction in downwind concentration is a result of both increased dilution with air, because of a reduced vaporization rate, and the increased buoyancy of the vapor cloud. This latter effect is caused by the vapor being warmed as it rises through the blanket by heat transfer from the foam and by the heat of solution of ammonia in water; the warmed vapor cloud will have greater buoyancy and will disperse in an upward direction more rapidly.

The extent of the downwind reduction in concentration will depend on the type of foam used. Research in this area has indicated that foams with a medium to high expansion ratio (75 to 350:1) give significantly better results than do foams with low expansion ratios (6 to 8:1) (40,41). The expansion ratio is the ratio of the volume of foam produced to the volume of solution fed to the foam-generating device. Furthermore, a high expansion foam will cause a smaller initial increase in boil off than a low expansion foam.

Regardless of the type of foam used, the slower the drainage rate of the foam, the better its performance will be. A slow-draining foam will spread more evenly, show more resistance to temperature and pH effects, and collapse more slowly. The initial cost of a slowly draining foam may be higher than that of other foams, but a cost-effective system will be realized in superior performance.

4.5.3 Mitigation Techniques for Ammonia Vapor (43,44)

The extent to which the escaped ammonia vapor can be removed or dispersed in a timely manner will be a function of the quantity of vapor released, the ambient conditions, and the physical characteristics of the vapor cloud. The behavior and characteristics of the ammonia cloud will be dependent on a number of factors. These include the physical state of the ammonia before its release, the location of the release, and the atmospheric and environmental conditions; a number of predictive dispersion models have been developed. In spite of the lower specific gravity of pure ammonia vapor, large accidental

releases of ammonia have often resulted in the formation of ammonia-air mixtures that are denser than the surrounding atmosphere. This type of vapor cloud is especially hazardous, because it will spread laterally and remain close to the ground.

The primary means of dispersing as well as removing ammonia vapor from the air is by using water sprays or fogs. The water is applied to the vapor cloud with hand-held hoses and/or stationary water-spray barriers. For effective absorption, it is important to direct waterfog or spray nozzles from a downwind direction to avoid driving the vapors downwind more quickly. Other important factors relating to the effectiveness of water sprays are the distance of the nozzles from the point of release, the fog pattern, nozzle flow rate, pressure, and nozzle rotation. If the right strategy is followed, a "capture zone" can be created downwind of the release into which the ammonia vapor will drift and be absorbed. In low wind conditions, two fog nozzles should be placed upwind of the release to ensure that the ammonia cloud keeps moving downwind against the water fog nozzle pressures. If water fog is used to absorb ammonia vapors from a diked area containing spilled liquid ammonia, great care must be taken not to direct water into the liquid ammonia itself.

Water-spray barriers consist of a series of spray nozzles that can be directed either up or down. If placed 30-40 feet from the point of ammonia release, these barriers are very effective in absorbing the ammonia vapors passing through without distorting the ammonia cloud (43). Several fog nozzles may be situated farther downwind to absorb the remainder of the vapors getting through.

In general, techniques used to disperse or control vapor emissions should be simple and reliable. In addition to the mitigation techniques discussed above, physical barriers such as buildings and rows of trees will help to contain the vapor cloud and control its movement. Hence, reducing the consequences of a hazardous vapor cloud can actually begin with a carefully planned layout of the facilities.

4.6 OPERATION AND MAINTENANCE PRACTICES

Accidental releases of toxic materials result not only from deficiencies of design but also from deficiencies of operation. Thus safe operation of plants using ammonia requires competent and experienced managers and staff, in addition to a well-considered and fully understood system of work.

Employees should be trained about the important aspects of handling ammonia, including: the proper means of handling and storing, hazards resulting from improper use and handling, prevention of spills, cleanup procedures, maintenance procedures, and emergency procedures. Well- defined and planned practices and procedures can reduce the possibility of an accidental release and the magnitude of an accidental release, if it should occur.

To reduce the chances for an accidental release, proper maintenance and modification programs should be a normal part of plant operation and design procedures. Maintenance should be based on a priority system to ensure that the most critical equipment is taken care of first. Strict procedures should apply to process modifications to ensure that modifications do not create unintended hazards. Inspections and nondestructive testing of vessels, piping, and machinery should be conducted periodically to detect small flaws that could eventually result in a major release.

4.7 CONTROL EFFECTIVENESS

It is difficult to quantify the control effectiveness of preventive and protective measures to reduce the probability and magnitude of accidental releases. Preventive measures, which may involve numerous combinations of process design, equipment design, and operational measures, are especially difficult to quantify because they reduce a probability rather than a physical quantity of a chemical release. Since protective measures are more analogous

to traditional pollution control technologies, they may be easier to quantify in terms of their efficiency in minimizing the adverse effects of a chemical.

Preventive measures reduce the probability of an accidental release by increasing the reliability of both process systems operations and equipment. Control effectiveness can thus be expressed for both the qualitative improvements and the quantitative improvements through probabilities. Table 4-4 summarizes what appear to be some of the major design, equipment, and operational measures applicable to the primary hazards identified for the ammonia applications in the SCAQMD. The items listed in this table are for illustration only and do not necessarily represent a satisfactory control option for all cases. These control options appear to reduce the risk associated with an accidental release when viewed from a broad perspective; however, there are undoubtedly specific cases where these control options will not be appropriate. Each case must therefore be evaluated individually.

4.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of control and for specific release prevention and protection measures that might be found in the SCAQMD for ammonia storage and process facilities. The estimates are presented first, followed by a discussion of the bases for the estimates.

4.8.1 Prevention and Protection Measures

Preventive measures reduce the probability of an accidental release from a process or storage facility by increasing the reliability of both process systems operations and equipment. Along with an increase in the reliability of a system is an increase in the capital and annual costs associated with incorporating prevention and protection measures into a system. Table 4-5 presents costs for some of the major design, equipment, and operational measures applicable to the primary hazards identified in Table 4-4 for the ammonia applications in the SCAQMD.

TABLE 4-4. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR AMMONIA RELEASES

Hazard Area	Prevention/Protection
Ammonia flow control	Redundant flow control loops; Minimal overdesign of feed systems
Temperature sensing and cooling medium flow control	Redundant temperature sensors; Interlock flow switch to shut off ammonia feed on loss of cooling, with relief venting to emergency scrubber system
Temperature sensing and heating medium flow control	Redundant temperature sensors; Interlock flow switch to shut off ammonia feed on loss of heating, with relief venting to emergency scrubber system
Overpressure	Redundant pressure relief; not isolatable; adequate size; discharge not restricted
Corrosion	Increased monitoring with more frequent inspections; use of corrosion coupons; visual inspections; non-destructive testing
Reactor and reboiler temperatures	Redundant temperature sensing and alarms
Overfilling	Redundant level sensing, alarms and interlocks; training of operators
Atmospheric releases from relief discharges	Emergency vent scrubber system
Storage tank or line rupture	Diking; foams; dilution; neutralization; water sprays; enclosure vented to emergency scrubber system

TABLE 4-5. ESTIMATED TYPICAL COSTS OF MAJOR PREVENTION AND PROTECTION MEASURES FOR AMMONIA RELEASE[a]

Prevention/Protection Measure	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Flow control loop	4,000-6,000	500-750
Temperature sensor	250-400	30-50
Pressure relief		
- relief valve	1,000-2,000	120-250
- rupture disk	1,000-1,200	120-150
Interlock system for flow shut-off	1,500-2,000	175-250
Alarm system	250-500	30-75
Level sensor		
- liquid level gauge	1,500-2,000	175-250
- load cell	10,000-15,000	1,300-1,900
Physical barriers		
- curbing	750-1,000	120-150
- 3 ft. retaining wall	1,500-2,000	175-250
Diking (based on a 10,000 gal. tank)		
- 3 ft. high	1,200-1,500	150-175
- top of tank height, 10 ft.	7,000-7,500	850-900
Increased corrosion inspection[b]		200-400

[a]Based on a 10,000 gallon fixed ammonia storage tank system and a 10 tons/day ammonia stripper system.

[b]Based on 10-20 hours @ $20/hr.

4.8.2 Levels of Control

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. At a minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations; however, additional measures can be taken to provide extra protection against an accidental release.

The levels of control concept provides a means of assigning costs to increased levels of prevention and protection. The minimum level is referred to as the "Baseline" system, which consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

The second level of control is "Level 1," which includes the baseline system with added modifications, such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

The third level of control is "Level 2". This system incorporates both the "Baseline" and "Level 1" systems with additional modifications designed specifically for the prevention of an accidental release, such as alarm and interlock systems. The extra accidental release prevention measures incorporated into "Level 2" are reflected in its cost, which is much higher than that of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures applied must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases

the complexity of a system. In some cases the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction along with proper operational practices are needed to assure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in these tables appropriate. An actual system is likely to incorporate some items from each of the levels of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, not to provide an equipment check list.

Levels of control cost estimates were prepared for a 25-ton fixed ammonia storage tank system with a 10,000 gal capacity and a waste water treatment ammonia stripper system with a 10 tons/day ammonia recovery rate. These systems are representative of storage and process facilities that might be found in the SCAQMD.

4.8.3 Cost Summaries

Table 4-6 summarizes the total capital and annual costs for each of the three levels of controls for the ammonia storage system and the ammonia stripper system. The costs presented correspond to the systems described in Tables 4-7 and 4-8. Each of the level costs include the cost of the basic system plus any added controls. Specific cost information and breakdown for each level of control for both the storage and process facilities are presented in Tables 4-9 through 4-14.

4.8.4 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the ammonia storage and the ammonia stripper systems are presented in Tables 4-15 through 4-22.

TABLE 4-6. SUMMARY COST ESTIMATES OF POTENTIAL LEVELS OF CONTROLS FOR AMMONIA STORAGE TANK AND STRIPPER

System	Level of Control	Total Capital Cost (1986 $)	Total Annual Cost (1986 $/yr)
Ammonia Storage Tank; 25 ton Fixed Ammonia Tank with 10,000 gal. Capacity	Baseline	215,000	26,000
	Level #1	553,000	65,000
	Level #2	1,254,000	146,000
Waste Water Treatment Ammonia Stripper with 10 tons/day Ammonia Recovery	Baseline	430,000	59,000
	Level #1	948,000	120,000
	Level #2	1,760,000	197,000

TABLE 4-7. EXAMPLE OF LEVELS OF CONTROL FOR AMMONIA STORAGE TANK

Process: 25 ton fixed ammonia storage tank
10,000 gal

Controls	Baseline	Level No. 1	Level No. 2
Process:	None	None	None
Flow:	Single check-valve on tank-process feed line.	Add second check valve.	Add a reduced-pressure device[a] with internal air gap and relief vent to containment tank or scrubber.
Temperature:	None	None	Add temperature indicator.
Pressure:	Single pressure relief valve, vent to atmosphere. Provide local pressure indicator.	Add second relief valve, secure non-isolatable. Vent to limited scrubber.	Add rupture disks under relief valves. Provide local pressure indication on space between disk and valve.
Quantity:	Local level indicator.	Add remote level indicator.	Add level alarm. Add high-low level interlock shut-off for both inlet and outlet lines.
Location:	Away from traffic.	Away from traffic and flammables.	Away from traffic, flammables, and other hazardous processes.
Materials of Construction:	Carbon steel	Carbon steel with increased corrosion allowances. (1/8 inch)	Type 316 SS.
Vessel:	Tank pressure specification: 250 psig.	Tank pressure specification: 300 psig.	Tank pressure specification: 375 psig.

(Continued)

[a]A reduced pressure device is a modified double check valve.

TABLE 4-7 (Continued)

Process: 25 ton fixed ammonia storage tank
10,000 gal

Controls	Baseline	Level No. 1	Level No. 2
Piping:	Schedule 40 carbon steel.	Schedule 80 carbon steel.	Schedule 80 Type 316 stainless steel.
Process Machinery:	Centrifugal pump, carbon steel, stuffing box seal.	Centrifugal pump, 316 SS construction, double capacity mechanical seal.	Magnetically-coupled centrifugal pump, 316 SS, construction.
Enclosures:	None	Steel building.	Concrete building.
Diking:	None	3 ft. high.	Top of tank height, 10 ft.
Scrubbers:	None	Water scrubber.	Same
Mitigation:	None	Water sprays.	Same

TABLE 4-8. EXAMPLE OF LEVELS OF CONTROL FOR AMMONIA STRIPPER

Process: Waste Water Treatment

Basis: 10 tons/day ammonia recovery plant

Controls	Baseline	Level No. 1	Level No. 2
Process:	Adequate temperature and flow control.	Enhanced temperature and flow control.	Computer control of process. Use of interlock systems.
Temperature:	Provide local temperature control.	Add redundant temperature sensors and alarms. Add remote temperature indicator.	Add computer control. Add temperature switch and back-up cooling system.
Pressure:	Provide local pressure control. Single pressure relief valve. Vent to atmosphere.	Add redundant pressure sensors. Add second relief valve. Vent to limited scrubber.	Add computer control. Add rupture disks under relief valves and provide local and remote pressure indicator on space between disk and valve.
Flow:	Provide local flow control on stripper feed and heating medium to reboiler.	Add redundant flow control loops.	Add computer control. Add interlock flow switch to shut off feed on loss of cooling medium.
Quantity:	None	None	None
Mixing:	None	None	None
Corrosion:	Visual inspections.	Same	Same
Composition:	None	None	None
Materials of Construction:	Carbon steel.	Carbon steel with added corrosion allowance.	Type 316 stainless steel.

(Continued)

TABLE 4-8 (Continued)

Process: Waste Water Treatment

Basis: 10 tons/day ammonia Recovery Plant

Controls	Baseline	Level No. 1	Level No. 2
Vessel:	Pressure specification: 250 psig.	Pressure specification: 300 psig.	Pressure specification: 375 psig.
Piping:	Schedule 40 carbon steel.	Schedule 80 carbon steel.	Schedule 80 Type 316 stainless steel.
Process Machinery:	Centrifugal pump, carbon steel construction, stuffing box.	Centrifugal pump. Type 316 stainless steel construction, double capacity mechanical seal.	Magnetically-coupled centrifugal pump, Type 316 stainless steel construction.
Protective Barriers:	None	Curbing around stripper.	3 ft. high retaining wall.
Scrubbers:	None	Water scrubber.	Same
Mitigation:	None	Water sprays.	Same

TABLE 4-9. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE AMMONIA STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	186,000	22,000
Piping and Valves:		
Pipework	4,500	520
Check Valve	520	60
Ball Valves (5)	3,200	370
Excess Flow Valves (2)	950	110
Angle Valves (2)	3,600	420
Relief Valve	2,000	230
Process Machinery:		
Centrifugal Pump	10,000	1,200
Instrumentation:		
Pressure Gauges (4)	1,500	170
Liquid Level Gauge	1,500	170
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
Total Costs	215,000	26,000

TABLE 4-10. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 AMMONIA STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	220,000	26,000
Piping and Valves:		
Pipework	12,000	1,300
Check Valve	1,100	120
Ball Valves (5)	3,200	370
Excess Flow Valves (2)	950	110
Angle Valves (2)	3,600	420
Relief Valves (2)	4,000	460
Process Machinery:		
Centrifugal Pump	20,000	2,300
Instrumentation:		
Pressure Gauges (4)	1,500	170
Flow Indicator	3,700	430
Load Cell	1,500	170
Remote Level Indicator	1,900	220
Enclosures:		
Steel Building	10,000	1,200
Scrubbers:		
Water Scrubber	268,000	31,000
Diking:		
3 ft	1,300	160

(Continued)

TABLE 4-10 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		30
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		35
Valve Maintenance		400
Total Costs	553,000	65,000

TABLE 4-11. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 AMMONIA STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	877,000	102,000
Piping and Valves:		
Pipework	6,000	680
Reduced Pressure Device	2,700	310
Ball Valves (5)	3,200	370
Excess Flow Valves (2)	950	110
Angle Valves (2)	3,600	420
Relief Valves (2)	4,000	460
Rupture Disks (2)	1,100	130
Process Machinery:		
Centrifugal Pump	32,000	3,700
Instrumentation:		
Temperature Indicator	2,200	260
Pressure Gauges (6)	2,200	260
Flow Indicator	3,700	430
Load Cell	16,000	1,800
Remote Level Indicator	1,900	220
Level Alarm	740	90
High-Low Level Shutoff	1,900	220
Enclosures:		
Concrete Building	19,000	2,200
Scrubbers:		
Alkaline Scrubber	268,000	31,000
Diking:		
10 ft High Concrete Dike	7,400	870

(Continued)

TABLE 4-11 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		50
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		35
Valve Maintenance		400
Total Costs	1,254,000	146,000

TABLE 4-12. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE WASTE WATER TREATMENT AMMONIA STRIPPER

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Vessels and Machinery:		
Stripping Column		
Reboiler and Condenser		
Centrifugal Pumps (3)		
Total Vessels and Machinery[a]	260,000	31,000
Piping and Valves:	117,000	14,000
Instrumentation:[a]	53,000	6,000
Maintenance and Inspections:[a]		8,000
Total Costs	430,000	59,000

[a]Costs are based on using cost factors from Peters and Timmerhaus (45) and a total fixed capital cost of $1.8 million (1986 basis) (13) for a 10 tons/day ammonia recovery plant.

TABLE 4-13. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 WASTE WATER TREATMENT AMMONIA STRIPPER

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Vessels and Machinery:		
Stripping Column		
Reboiler and Condenser		
Centrifugal Pumps (3)		
Total Vessels and Machinery[a]	470,000	56,000
Piping and Valves:[a]	147,000	17,000
Relief Valve	2,000	240
Instrumentation:[a]	53,000	6,000
Temperature Sensor	360	45
Temperature Alarm	360	45
Remote Temperature Indicator	1,800	220
Remote Pressure Indicator	1,800	220
Flow Control Loops (2)	11,000	1,300
Diking:		
Curbing Around Reactor	1,200	150
Scrubber:		
Water Scrubber	260,000	31,000
Maintenance and Inspections:[a]		8,000
Relief Valve Inspection		15
Total Costs	948,000	120,000

[a]Costs are based on using cost factors from Peters and Timmerhaus (45) and a total fixed capital cost of $1.8 million (1986 basis) (13) for a 10 tons/day ammonia recovery plant.

Table 4-14. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 WASTE WATER TREATMENT AMMONIA STRIPPER

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Vessels and Machinery:		
Stripping Column		
Reboiler and Condenser		
Centrifugal Pumps (3)		
Total Vessels and Machinery[a]	1,049,000	126,000
Piping and Valves[a]:	167,000	20,000
Relief Valve (2)	7,400	880
Rupture Disk (2)	2,300	280
Instrumentation[a]:	53,000	6,400
Temperature Sensor	360	45
Temperature Alarm	360	45
Temperature Switch	540	65
Remote Temperature Indicator	1,800	220
Remote Pressure Indicator	1,800	220
Flow Control Loops (2)	11,000	1,300
Flow Interlock System	1,800	220
All Loops on Computer Control[b]	201,000	2,400
Diking:		
3 ft. High Retaining Wall	3,000	360
Scrubber:		
Water Scrubber	260,000	31,000
Maintenance and Inspections[a]:		8,000
Relief Valve Inspection		25
Total Costs	1,760,000	197,000

[a] Costs are based on using cost factors from Peters and Timmerhaus (45) and a total fixed capital cost of $1.8 million (1986 basis) (13) for a 10 tons/day ammonia recovery plant.

[b] Computer control costs are determined using cost estimating factors from Valle-Riestra (46).

TABLE 4-15. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH AMMONIA STORAGE SYSTEM

Equipment Item		Equipment Specifications	Reference
VESSELS:			
Storage Tank	Baseline:	10,000 gal Carbon Steel Storage Tank, 250 psig rating	45,47,48,49
	Level #1:	10,000 gal Carbon Steel with 1/8 in. Corrosion Protection, 300 psig	
	Level #2:	10,000 gal Type 316 Stainless Steel, 375 psig rating	
PIPING AND VALVES:	Baseline:	4 in. Schedule 40 Carbon Steel	50
Pipework	Level #1:	4 in. Schedule 80 Carbon Steel	
	Level #2:	4 in. Schedule 80 Type 316 Stainless Steel, 100 ft. in Length	
Check Valve	4 in. Vertical Lift Check Valve, Carbon Steel Construction		47,51
Ball Valve	4 in. Class 300, Carbon Steel Body, Monel® Ball and Trim		45,47,51
Excess Flow	4 in. Standard Valve		47
Angle Valve	4 in. Carbon Steel Construction		52
Relief Valve	2 in. x 3 in. Class 300 Inlet and Outlet Flange, Angle Body, Closed Bonnet with Screwed Cap, Carbon Steel Body		47
Reduced Pressure Valve	Double Check Valve Type Service with Internal Air Gap and Relief Valve		45
Rupture Disk	2 in. Monel® Disk and Carbon Steel Holder		48,53,54
PROCESS MACHINERY:			
Centrifugal Pump	Baseline:	Single Stage, Carbon Steel Construction, Stuffing Box	47,55
	Level 1:	Single Stage, Type 316 Stainless Steel Construction, Double Mechanical Seal	47,55
	Level 2:	Type 316 Stainless Steel Construction, Magnetically-coupled	47,55

(Continued)

TABLE 4-15 (Continued)

Equipment Item	Equipment Specifications	Reference
INSTRUMENTATION:		
Pressure Gauge	Diaphragm Sealed, Hastelloy C Diaphragm, 0-1,000 psi	
Liquid Level Gauge	Differential Pressure Type	45,56
Temperature Indicator	Thermocouple, Thermowell, Electronic Indicator	45,47,56
Flow Indicator	Differential Pressure Cell and Transmitter and Associated Flowmeter	45,47
Level Indicator	Differential Pressure Type Indicator	45,47,56
Load Cell	Electronic Load Cell	45,56,57
High-low Level Shutoff	Solenoid Valve, Switch, and Relay System	45,47,56
ENCLOSURE:		
Building	Level #1: 26-Gauge Steel Walls and Roof, Door, Ventillation System	52
	Level #2: 10 in. Concrete Walls, 26-Gauge Steel Roof	59
SCRUBBER:	Level #1 and 2: Spray Tower, Monel® Construction, 4 ft. x 12 ft., Water Sprays	
DIKING:	Level #1: 6 in. Concrete Walls, 3 ft. high	52
	Level #2: 10 in. Concrete Walls, Top of Tank Height	

TABLE 4-16. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE AMMONIA STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Storage Tank	86,000	39,000	125,000	44,000	186,000
Piping and Valves:					
Pipework	900	2,100	3,000	1,100	4,500
Check Valves	320	30	350	120	520
Ball Valves (5)	2,000	150	2,150	750	3,200
Excess Flow Valves (2)	600	40	640	220	950
Angle Valves (2)	2,400	40	2,440	860	3,600
Relief Valve	1,300	50	1,330	460	2,000
Process Machinery:					
Centrifugal Pump	4,900	2,100	7,000	2,500	11,000
Instrumentation:					
Pressure Gauges (4)	800	200	1,000	350	1,500
Liquid Level Gauge	800	200	1,000	350	1,500
Total Costs	100,000	44,000	144,000	50,000	215,000

TABLE 4-17. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 AMMONIA STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Storage Tank	102,000	46,000	148,000	52,000	220,000
Piping and Valves:					
Pipework	5,300	2,500	7,800	2,700	12,000
Check Valves	640	60	700	250	1,100
Ball Valves (5)	2,000	150	2,150	750	3,200
Excess Flow Valves (2)	600	40	640	220	950
Angle Valves (2)	2,400	40	2,400	860	3,600
Relief Valve (2)	2,600	100	2,660	920	4,000
Process Machinery:					
Centrifugal Pump	9,300	4,000	13,300	4,700	20,000
Instrumentation:					
Pressure Gauges (4)	800	200	1,000	350	1,500
Flow Indicator	2,000	500	2,500	880	3,700
Liquid Level Gauge	800	200	1,000	350	1,500
Remote Level Indicator	1,000	250	1,250	440	1,900
Enclosures:					
Steel Building	4,600	2,300	6,900	2,400	10,000
Scrubbers:					
Water Scrubber	125,000	56,000	181,000	63,000	268,000
Diking:					
3 ft. High Concrete Diking	390	520	910	320	1,300
Total Costs	259,000	113,000	372,000	130,000	553,000

TABLE 4-18. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 AMMONIA STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Storage Tank	407,000	183,000	590,000	207,000	877,000
Piping and Valves:					
Pipework	1,400	2,600	4,000	1,400	6,000
Reduced Pres. Device	1,600	200	1,800	630	2,700
Ball Valves (5)	2,000	150	2,150	750	3,200
Excess Flow Valves (2)	600	40	640	220	950
Angle Valves (2)	2,400	40	2,440	860	3,600
Relief Valve (2)	2,600	100	2,660	920	4,000
Rupture Disks (2)	650	75	725	250	1,100
Process Machinery:					
Centrifugal Pump	15,000	6,400	21,400	7,500	32,000
Instrumentation:					
Temperature Indicator	1,200	300	1,500	530	2,200
Pressure Gauges (6)	1,200	300	1,500	530	2,200
Flow Indicator	2,000	500	2,500	880	3,700
Load Cell	8,400	2,100	10,500	3,700	16,000
Remote Level Indicator	1,000	250	1,250	440	1,900
Level Alarm	400	100	500	180	740
High-Low Level Shutoff	1,000	250	1,250	440	1,900
Enclosures:					
Concrete Building	6,100	6,600	12,700	4,500	19,000
Scrubbers:					
Water Scrubber	125,000	56,000	181,000	63,000	268,000
Diking:					
10 ft. High Concrete Dike	2,200	2,850	5,000	1,800	7,400
Total Costs	582,000	262,000	844,000	295,000	1,254,000

TABLE 4-19. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH WASTE WATER TREATMENT AMMONIA STRIPPING PROCESS

Equipment Item	Equipment Specification	Reference
VESSELS AND MACHINERY:	Ammonia Stripper and Associated Reboiler and Condenser as Defined in Reference	13
PIPING AND VALVES:		
Pipework	Baseline: 4 in. Schedule 40 Carbon Steel, 360 ft. Level #1: Schedule 80 Carbon Steel Level #2: Schedule 80 Type 316 Stainless Steel	50
Relief Valve	2 in. x 3 in. Class 300 Inlet and Outlet Flanges, Angle Body, Closed Bonnet with Screwed Cap, Carbon Steel Body	47
Rupture Disk	2 in. Monel® Disk and Carbon Steel Holder	48,53,54
INSTRUMENTATION:		
Temp. Sensor	Thermocouple and Associated Thermowell	45,47,56
Temp. Alarm	Indicating and Audible Alarm	47,52,58
Temp. Switch	Two-Stage Switch with Independently Set Actuation	45,56
Remote Temp. Indicator	Transmitter and Associated Electronic Indicator	45,56
Remote Press. Indicator	Transducer, Transmitter and Electronic Indicator	45,56
Flow Control Loop	4 in. Globe Control Valve, Flowmeter and PID Controller	45,56
Flow Interlock System	Solenoid Valve, Switch, and Relay System	45,47,52,56
DIKING:		
	Level #1: 6 in. High Concrete Curbing Level #2: 3 ft. High Concrete Retaining Wall	52
SCRUBBER:	Level #1 and #2: Spray Tower, Monel® Construction 4 ft. x 12 ft., Water Sprays	59

TABLE 4-20. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE WASTE WATER TREATMENT AMMONIA STRIPPER

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Equipment:					
Vessels and Machinery:					
Stripping column					
Reboiler and Condenser					
Centrifugal Pumps (3)					
Total Vessels and Mach.[a]	125,000	56,000	181,000	45,000	260,000
Piping and Valves:[a]	45,000	37,000	82,000	20,000	117,000
Instrumentation:[a]	28,000	9,000	37,000	9,000	53,000
Total Costs	198,000	102,000	300,000	74,000	430,000

[a]Costs are based on using cost factors from Peters and Timmerhaus (45) and a total fixed capital cost of $1.8 million (1986 basis) (13) for a 10 tons/day ammonia recovery plant.

TABLE 4-21. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 WASTE WATER TREATMENT AMMONIA STRIPPER

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Equipment:					
Vessels and Machinery:					
Stripping column					
Reboiler and Condenser					
Centrifugal Pumps (3)					
Total Vessels and Mach.[a]	226,000	101,000	327,000	82,000	470,000
Piping and Valves:[a]	77,000	25,000	102,000	25,000	147,000
Relief Valve	1,300	50	1,350	340	2,000
Instrumentation:[a]	28,000	9,000	37,000	9,000	53,000
Temperature Sensor	200	50	250	60	360
Temperature Alarm	200	50	250	60	360
Remote Temperature Indicator	1,000	250	1,250	310	1,800

(Continued)

[a]Costs are based on using cost factors from Peters and Timmerhaus (45) and a total fixed capital cost of $1.8 million (1986 basis) (13) for a 10 tons/day ammonia recovery plant.

TABLE 4-21 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Remote Press. Indicator	1,000	250	1,250	310	1,800
Flow Control Loops (2)	6,000	1,500	7,500	1,900	11,000
Diking:					
Curbing Around Reactor	500	350	850	210	1,200
Scrubber:					
Water Scrubber	125,000	56,000	181,000	45,000	260,000
Total Costs	466,000	194,000	660,000	164,000	948,000

TABLE 4-22. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 WASTE WATER TREATMENT AMMONIA STRIPPER

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Equipment:					
Vessels and Machinery:					
Stripping column					
Reboiler and Condenser					
Centrifugal Pumps (3)					
Total Vessels and Mach.[a]	504,000	226,000	730,000	182,000	1,049,000
Piping and Valves:[a]	87,000	29,000	116,000	29,000	167,000
Relief Valve (2)	5,000	100	5,100	1,300	7,400
Rupture Disk (2)	1,500	100	1,600	400	2,300
Instrumentation:[a]	28,000	9,000	37,000	9,000	53,000
Temperature Sensor	200	50	250	60	360
Temperature Alarm	200	50	250	60	360

(Continued)

[a]Costs are based on using cost factors from Peters and Timmerhaus (45) and a total fixed capital cost of $1.8 million (1986 basis) (13) for a 10 tons/day ammonia recovery plant.

TABLE 4-22 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Temperature Switch	300	75	375	95	540
Remote Temperature Indicator	1,000	250	1,250	310	1,800
Remote Pressure Indicator	1,000	250	1,250	310	1,800
Flow control Loops (2)	6,000	1,500	7,500	1,900	11,000
Flow Interlock System	1,000	250	1,250	310	1,800
All Loops on Computer Control[b]	105,000	35,000	140,000	35,000	201,000
Diking:					
3ft. high retaining wall	900	1,200	2,100	530	3,000
Scrubber:					
Water Scrubber	125,000	56,000	181,000	45,000	260,000
Total Costs	866,000	359,000	1,225,000	305,000	1,760,000

[b]Computer control costs are determined using cost estimating factors from Valle-Riestra (46).

4.8.5 Methodology

Format for Presenting Cost Estimates--

Tables are provided for control schemes associated with storage and process facilities for ammonia showing capital, operating, and total annual costs. The tables are broken down into subsections comprising vessels, piping and valves, process machinery, instrumentation, and procedures and practice. Presenting the costs in this manner allows for easy comparison of costs for specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 4-23 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital, as shown in Table 4-23, begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the direct capital cost was available or was derived from uninstalled equipment costs by computing costs of installation separately. To obtain the total fixed capital cost, other costs obtained by using factors are added to the total direct costs.

The first group of other cost elements is indirect costs. These include engineering and supervision, construction expenses, and various other expenses such as administration expenses. These costs are computed by multiplying total direct costs by a factor shown in Table 4-23. The factor is approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and for individual technologies within an area. Appropriate factors based on judgement and experience were selected for this report.

TABLE 4-23. FORMAT FOR TOTAL FIXED CAPITAL COST

Item No.	Item	Cost
1	Total Material Cost	-
2	Total Labor Cost	-
3	Total Direct Cost	Items 1 + 2
4	Indirect Cost Items (Engineering & Construction Expenses)	0.35 x Item 3[a]
5	Total Bare Module Cost	Items (3 + 4)
6	Contingency	(0.05 x Item 5)[b]
7	Contractor's Fee	0.05 x Item 5
8	Total Fixed Capital Cost	Items (5 + 6 + 7)

[a]For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b]For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

When the indirect costs are added to the total direct costs, total bare module cost is obtained. Some additional cost elements, such as contractor's fee and contingency, are calculated by applying and adding appropriate factors to the total bare module cost, as shown in Table 4-23, to obtain the total fixed capital cost.

Annual Cost--Annual costs are obtained for each equipment item by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 4-24 defines the cost elements and the appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. The sum of these individual costs equals the total annual cost.

Sources of Information--

Costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. The objective of this effort was to present cost levels for ammonia process and storage facilities using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (45), Chemical Engineering (60), and Valle-Riestra (46) supplemented by other sources and references where necessary. Adjustments were made to update all costs to a June 1986 dollar basis. For some equipment items, well-documented costs were not available and they had to be developed from component costs.

Costs in this document reflect the "typical" or "average" representation for specific equipment items. This restricts the use of data in this report to:

- Preliminary estimates used for policy planning;
- Comparison of relative costs of different levels or systems; and

TABLE 4-24. FORMAT FOR TOTAL ANNUAL COST

Item No.	Item	Cost
1	Total Direct Cost	-
2	Capital Recovery on Equipment Items	0.163 x Item 1
3	Maintenance Expense on Equipment Items	0.01 x Item 1
4	Total Procedural Items	-
5	Total Annual Cost	Items (2 + 3 + 4)

- Approximations of costs that might be incurred for a specific application.

The costs in this report are considered to be "order of magnitude" with a ±50 percent margin. This is because costs are based on preliminary estimates and many are updated from literature sources. Large departures from the design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary more than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to those from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base-year dollars may be adjusted to dollars for another year by applying cost indices as shown in the following equation:

$$\text{new base-year cost} = \text{old base-year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The Chemical Engineering (CE) Plant Cost Index was used to update costs for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were

used in determining the costs associated with vessels, piping systems, scrubbers, diking, and enclosures. The techniques used are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit free on board (f.o.b.), with carbon steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (45):

$$\text{Cost} = [50(\text{Weight of Vessel in Pounds})^{-0.34}][\text{Weight of Vessel in Pounds}]$$

The vessel weight is determined using appropriate design equations, as given by Peters and Timmerhaus (45) that allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight of nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different materials of construction, as given in Peters and Timmerhaus (45). Vessel costs are updated using cost factors. Finally, a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained from cost information and data presented by Yamartino (50). A simplified approach is used in which it is assumed that a certain length of piping containing a given number of valves, flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (50) permit cost determinations for various lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's Manual (52) for reinforced concrete walls. The following assumptions were made to determine the costs. The dike contains the entire contents of a tank in the event of a leak

or release. Two dike sizes are possible: a three-foot high dike, six-inches thick and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are not volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures--Enclosure costs were estimated using Mean's Manual (52) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten-inches thick with a 26-gauge steel roof and a metal door. The steel building has 26 gauge roofing and siding and metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals.

Scrubbers--Scrubber costs were estimated using the following equation from the Gard (59) manual for spray towers based on the actual cubic feet per minute of flow at a chamber velocity of 600 feet/minute.

$$\text{Costs} = 0.235 \times (\text{ACFM} + 43{,}000)$$

A release rate of 10,000 ft^3/minute was assumed for the storage vessel systems and an appropriate rate was determined for process system based on the quantity of hazardous chemicals present in the system at any one time. For the ammonia stripper system, a release rate of 10,000 ft^3/minute was assumed. In addition to the spray tower, the costs also include pumps and a storage tank for the scrubbing medium. The costs presented are updated to June 1986 dollars.

Installation Factors--

Installation costs were developed for all equipment items included in both the process and storage systems. The costs include both the material and labor costs for installation of a particular piece of equipment. The costs

were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost through the use of estimating factors obtained from Peters and Timmerhaus (45) and Valle-Riestra (46). Table 4-25 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per year rate of increase for labor and cost indices for materials associated with installation.

TABLE 4-25. FORMAT FOR INSTALLATION COSTS

Equipment Item	Factor or Reference
Vessels:	
Storage Tank	0.45
Expansion Tank	0.25
Piping and Valves:	
Pipework	Ref. 50
Expansion Loop	Ref. 47
Reduced Pressure Device	Ref. 47
Check Valves	Ref. 47
Gates Valves	Ref. 47
Ball Valves	Ref. 47
Excess Flow Valves	Ref. 47
Angle Valves	Ref. 52
Relief Valves	Ref. 47
Rupture Disks	Ref. 47
Process Machinery:	
Centrifugal Pump	0.43
Gear Pump	0.43
Instrumentation:	
All Instrumentation Items	0.25
Enclosures:	Ref. 52
Diking:	Ref. 52
Scrubbers:	0.45

SECTION 5

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APPENDIX A
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and/or results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Cavitation: The formation and collapse of vapor bubbles in a flowing liquid. Specifically the formation and collapse of vapor cavities in a pump when there is sufficient resistance to flow at the inlet side.

Containment/control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Creep failure: Failure of a piece of metal as a result of creep. Creep is time dependent deformation as a result of stress. Metals will deform when exposed to stress. High levels of stress can result in rapid deformation and rapid failure. Lower levels of stress can result in slow deformation and protracted failure.

Deadheading: Closing or nearly closing or blocking the discharge outlet or piping of an operating pump or compressor.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Hygroscopic: Readily absorbing and retaining moisture, usually in reference to readily absorbing moisture from the air.

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g. Hazard Identification.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine, or repackage, chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators, that would not be categorized as piping or vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A chemical is sometimes said to be "reactive", or have high "reactivity", without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX B

TABLE B-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume:	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	(psig)+14.696)x(6.895)
Temperature:	°F	°C*	(5/9)x(°F-32)
	°C	K*	°C+273.15
Caloric Value;	Btu/lb	kJ/kg	2.326
Enthalpy:	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	kg/m-s	0.001

*Calculate as indicated